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<td>T-PHYS-111411</td>
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<td>T-PHYS-104384</td>
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<td>X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Experiments and Lab</td>
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1 Master’s Program in Physics

Physics is one of the classical natural sciences. Studies of physics are geared towards scientific work as a physicist at universities and non-university research institutions as well as in industry. Our Master's program in physics is focused on research-oriented teaching, with lectures that are centered around modern research topics and the Master's thesis offering the opportunity for students to participate in state-of-the-art research work as central part of their education. However, the future field of work of physicists is not limited to scientific research. Physicists are in high demand by a broad variety of employers, both in industry and in the public sector. This is mainly due to their competences in analyzing, modeling, and solving problems in accordance with scientific standards. These competences can be used widely and represent the focus of education.

The Master's program of physics builds on a Bachelor's program of physics in which the foundations of the field are acquired. The consecutive Master's program of physics covers a wide range of topics, but also imparts in-depth and specialized knowledge. These topics are divided into:

A. Experimental Physics:
   - Condensed Matter
   - Nanophysics
   - Optics and Photonics
   - Experimental Particle Physics
   - Experimental Astroparticle Physics

B. Theoretical Physics:
   - Theoretical Particle Physics
   - Condensed Matter Theory

Students are given a variety of options to choose these topics; they are modeled as major, second major, and minor subjects in physics in the Master's program. In addition, courses from meteorology, climate physics, and geophysics may be chosen as second major or minor subjects. The program concludes with the Master's thesis, which includes an introduction to independent scientific work and a specialization phase. Master's studies can be aligned largely to the students' individual preferences and skills and allows a wide range of profiles, ranging from theory-focused work over instrumentation for physics experiment to data science.

To meet the requirements for admission to the Master's program in physics, a solid university education in physics is required, as conveyed in the Bachelor's program of physics at KIT or other German universities. The KIT Department of Physics has adopted corresponding regulations for admission to the Master's program.

1.1 Qualification Goals

1.1.1 Qualification Goals of the Master's Program

Graduates of the Master's program in physics know the scientific foundations of experimental and theoretical physics and have obtained in-depth knowledge of the state-of-the-art in their major, second major, and minor subjects in physics, which can be selected from a large range of subjects in experimental and theoretical physics as well as meteorology and geophysics (see above). They possess advanced knowledge in an additional subject outside of physics that can be selected from a large range of options. They know how to apply concepts of theoretical or experimental physics to research-related problems and how to search for solution strategies. In experimental physics, they are able to perform sophisticated physics experiments, to determine physics observables from measured data, to formulate models describing the data, and to derive predictions. Graduates specialized in theoretical physics know how to carry out complex calculations and to interpret the results within the framework of the theory studied. Based on the acquired knowledge, they are able to classify facts and subject areas professionally. Moreover, graduates can summarize scientific findings and research results in both written and oral form and present them in a didactically appealing way. Successful completion of the program allows for work in a variety of fields, including university and industrial research and development, data science and process optimization, or programming and hardware application. Graduates also are qualified to start doctoral studies in physics. KIT attaches particular value to research-oriented teaching. Master's students can choose from a large range of options to specialize according to their interests, in close contact to research within KIT's university mission or using the unique large-scale research facilities of KIT's Helmholtz mission.

The Bachelor's and Master's programs in physics at KIT are in line with the Bologna Process, offering full compatibility with corresponding programs at other universities within the European Higher Education Area. The combination of the Bachelor's program with the Master's program at KIT is equivalent to the former Diplom program. General qualification goals of Bachelor's and Master's programs in physics are defined by the Konferenz der Fachbereiche Physik (Association of Physics Departments of universities that are members of the German Rectors Conference) for all of Germany, taking into account international academic education and research. In this way, students can easily change their university in Germany and are guaranteed an internationally well-defined field of work.
1.1.2 Relevance for Sustainable Development Goals

The laws of physics are the fundamental basis of how the world around us functions. The understanding of physics principles is essential for reaching several of the UN sustainable development goals (SDGs, https://sdgs.un.org/goals). Examples of SDGs and their relation to the Master's program include

- #3 Good Health: Master's students are educated in physics technologies such as magnetic resonance imaging and particle detectors, which can be applied in medicine.
- #4 Quality Education: Graduates of the Master's program in physics are excellent educators and multipliers of knowledge in basic science.
- #5 Gender Equality: Increasing the number of women in science, technology, engineering and mathematics (STEM) subjects is a key goal of the KIT Physics Department, with measures including female professors as role models and gender-neutral language in all study programs.
- #7 Affordable and Clean Energy, and #8 Decent Work and Economic Growth: The Master's curriculum includes courses geared towards research on the physics foundations of technologies that support both future products and the global transition to affordable and clean energy, e.g., high-efficiency solar cells.
- #13 Climate Action: Master's students can study advanced topics of meteorology and climate physics, as well as geophysics as part of their individual course selection.

In addition to these direct relations to the SDGs, all courses in the physics curriculum transmit knowledge and skills which are directly or indirectly essential for sustainable development: The students acquire in-depth knowledge about physics principles, the scientific approach to problem solving, and modern techniques in data analysis and computation.

1.1.3 Qualification Goals of Individual Subjects

1.1.3.1 Major, Second Major, and Minor Subjects in Physics

Students decide the focus of their Master's studies and deepen their knowledge in selected subjects. Thanks to research-oriented teaching, they obtain knowledge that enables them to independently work on latest research topics. The major, second major, and minor subjects must be chosen from different fields. This allows students to gain deeper insight into their area of interest, while keeping a broad education. Students learn to deal with research-related issues and to use latest literature when searching for solution approaches. They familiarize with modern measurement methods and computing techniques needed for work on their Master's thesis.

1.1.3.2 Non-Physics Elective Subject

The non-physics elective subject may be a subject of mathematics, natural sciences, or engineering and can be chosen from courses offered by other KIT Departments. Master's students acquire expert skills in neighboring disciplines, opening up a wide range of opportunities in the labor market.

1.1.3.3 Advanced Physics Laboratory Course

The advanced physics laboratory course conveys knowledge about latest experimental methods and techniques. Students have advanced skills in setting up experiments and measuring and evaluating experimental data.

1.1.3.4 Advanced Seminar

Students hone their presentation techniques by giving an own presentation and listening to presentations of the other participants. They learn how to gather scientific material beyond typical textbook knowledge, cite sources correctly, select and arrange the material from a didactic point of view, structure their presentation, use latest presentation media, make their own presentation, and answer the questions of the audience.

1.1.3.5 Interdisciplinary Qualifications

Students acquire competencies beyond their discipline. The House of Competence (HoC), Zentrum für Angewandte Kulturwissenschaft (ZAK) and the Language Center (Sprachenzentrum) regularly offer modules in the areas of scientific English, patent law, project management, tutor programs, scientific writing, and public science.

1.1.3.6 Introduction to Scientific Methods and Specialization Phase

The subject "Introduction to Scientific Methods" teaches basic working methods for successful scientific research. These methods are independent of the specialization area, but are trained and taught to cope with a defined task (subject of the Master's thesis). The students are instructed by the future supervisor of their Master's thesis. Parallel to their studies, students attend seminars and colloquia in physics to obtain an overview of latest research issues. They can extend their knowledge by attending special lectures on issues that are not covered by their area of specialization and by having their questions answered by the lecturer. In the subject "Specialization Phase", the students independently work on a concrete task relating to their future Master's thesis. This may be the execution of measurements, the setup of a program, or the development of a theoretical approach. In this way, students learn essential techniques for work on their Master's thesis, which are specific to their area of specialization. Again, students are instructed by the future supervisor of their Master's thesis. In addition, students attend the seminar offered by the research area in which they will write their Master's thesis. Here, they learn to present their work and results to other researchers for critical discussion and to respond to suggestions for further action.
1.1.3.7 Master’s Thesis
In addition to the major, second major, and minor subject, the Master’s thesis is the central component of specialization and acquisition of in-depth knowledge. While working on their Master’s thesis, students learn to independently analyze a scientific problem, develop suitable solutions, interpret the findings, and present major results in writing. In addition, key competencies such as working in a planned and purposeful manner, measurement technology, documentation, team work, and team responsibility are acquired. The Master’s thesis is prepared by the introduction to independent scientific work and a specialization phase.

1.1.4 Credits
Course credits are defined on the module level according to the European Credit Transfer System (ECTS). One ECTS credit point corresponds to a time expenditure of about 30 hours. This time is divided into time spent attending, preparing for, and following up on lectures, exercises, and tutorials, as well as for preparing for the corresponding exams.

According to the Studies and Examination Regulations of the Master’s Program of Physics, 120 ECTS credit points must be achieved for the successful completion of the Master's program:

- Major in Physics: 20 ECTS credit points
- Second Major in Physics: 14 ECTS credit points
- Minor in Physics: 8 ECTS credit points
- Advanced Physics Laboratory Course: 6 ECTS credit points
- Non-Physics Elective: 8 ECTS credit points
- Interdisciplinary Qualifications: 4 ECTS credit points
- Specialization Phase: 15 ECTS credit points
- Introduction to Scientific Methods: 15 ECTS credit points
- Master’s Thesis: 30 ECTS credit points

1.2 Study Plan for the Master’s Program of Physics
1.2.1 Introduction
The Master’s program is designed to specialize and deepen the basic and methodological knowledge acquired during Bachelor’s program while maintaining its breadth. Master’s studies may be aligned largely to individual preferences and skills. Quality is assured by a mandatory Master’s thesis that is written within a period of six months (30 ECTS credit points). The standard period of study is four semesters, including work on the Master’s thesis. When the Master’s exam is passed, the academic degree of “Master of Science (M. Sc.)” is awarded by Karlsruhe Institute of Technology.

The sequence of the Master’s program in physics at KIT is specified below. Detailed rules for the organization of the program and exams are outlined in the Studies and Examination Regulations for the Master's Program of Physics of March 9, 2023. The official document (in German) and a legally non-binding English translation can be found on the website of the KIT Department of Physics (https://www.physik.kit.edu/english/studies/services/documents.php). If you have any questions regarding the examination regulations, the recognition of coursework and examinations, content of studies, or the admission to and registration for examinations, please contact the persons listed on website of the KIT Department of Physics.

Detailed descriptions of the courses and rules for performance reviews (“controls of success”, e.g., problem sheets, oral presentations) are given below.

1.2.2 Courses, Credits, and Grading
a) Major, Second Major, and Minor Subjects in Physics
Students can select their major, second major, and minor subjects from seven areas of physics that reflect the research activities of the KIT Department of Physics. The areas are divided into Experimental Physics (Field A: Condensed Matter, Nanophysics, Optics and Photonics, Experimental Particle Physics, Experimental Astroparticle Physics), and Theoretical Physics (Field B: Theoretical Particle Physics, Condensed Matter Theory). For further information on the research pursued in the KIT institutes with lecturers associated to the KIT Department of Physics please visit the department's website (https://www.physik.kit.edu/english/forschung/our_research.php).

In the major subject, the grade is determined by an individual oral exam covering material from the corresponding courses. A total of at least 20 ECTS credit points are required for admission to the exam. These are acquired by passing the controls of the success defined in this document. The advanced seminar (4 ECTS credit points, see below) may be used to reach the 20 ECTS credit points, but will not be covered by the oral examination.

In the second major subject, the controls of success are graded. These are defined in this document and may be oral exams (individual or group exams), short presentations (concurrent with lecture or in blocks at the end of the semester), short written papers about a specific topic, or written examinations. A total of at least 14 ECTS credit points is required for admission to the exam. The advanced seminar may be used to reach the 14 ECTS credit points, but will not be graded. The final grade is obtained as the credit point-weighted average of the individual grades.

No grade is assigned in the minor subject. Students are only required to pass the control of success for the chosen course, e.g., successful participation in exercise sections accompanying the lecture, oral exams, short presentations, short written
papers or written examinations. A total of at least 8 ECTS credit points is required, which may include the advanced seminar (4 ECTS credit points).

b) Advanced Physics Laboratory Course
The lecture program on experimental physics is complemented by a laboratory course (6 ECTS credit points, not graded) in which students perform advanced physics experiments, analyze the data and document the results.

c) Advanced Seminar
Students select an advanced seminar (4 ECTS credit points, not graded) in one of the three major, second major, and minor subjects. During the advanced seminar, expert knowledge is deepened in one of the fields and scientific presentation techniques are conveyed.

d) Non-Physics Elective Subject
The “Non-Physics Elective” may be chosen from courses offered by other KIT departments and requires at least 8 ECTS credit points. Courses in mathematics, natural sciences, or engineering are most often chosen. Course controls of success are graded.

e) Interdisciplinary Qualifications
In addition to integrative key competencies acquired as part of the Master's program, courses on interdisciplinary qualification that impart additive key competencies must be passed (4 ECTS credit points, not graded).

f) Introduction to Scientific Methods, Specialization Phase, and Master's Thesis
The Master's thesis in the fourth semester of the Master's program is prepared by a specialization phase (15 ECTS credit points, not graded) and an introduction to scientific work (15 ECTS credit points, not graded) in the third semester. Both subjects provide a sound basis and (in integrative form) key competencies for conducting research.

Calculation of the Overall Grade
The overall grade of the master's examination is calculated from the grade average weighted by credit points of the following subjects: Major in Physics (20 ECTS credit points), Second Major in Physics (14 ECTS credit points), Non-Physics Elective (8 ECTS credit points), and the Master's Thesis (30 ECTS credit points).

1.2.3 Organization of Subjects and Selection Rules

The Master's program in physics is designed to allow for curricula tailored to individual students within the framework of the subjects, research fields, and topics defined above. To provide additional flexibility, students only have to decide on the assignment of courses to the major, second major, and minor subjects in physics after completing the first year of their Master studies. Note however that the choice of courses is subject to additional selection rules to ensure scientific breadth and consistent curricula, as detailed below. Students are advised to contact the department's student advisor (https://www.physik.kit.edu/english/studies/services/guidance.php) or the examination committee to determine if their individual curriculum is compatible with these rules. Further independent counseling is provided by the student council.

Major, Second Major, and Minor Subjects in Physics

Students elect their major, second major, and minor subjects from courses offered by the KIT Department of Physics in the topics of experimental physics (Field A) and theoretical physics (Field B). The second major and minor subjects may also be chosen from a list of appropriate courses in meteorology or geophysics (Field C). The lists of courses below contain a few courses offered by other departments; these are marked "extern" (external). Additional lectures on topics close to physics offered by other departments (e.g., on non-linear optics) may be combined in a subject upon approval by the examination committee.

- **Major**: A core curriculum is established for each topic with one or more required courses for the selection as a major subject. These courses are supplemented by other courses within the topic and optionally the advanced seminar for a total of at least 20 ECTS credit points.

- **Second Major**: Students elect a combination of courses from a different topic (and optionally the advanced seminar) as their second major subject for a total of at least 14 ECTS credit points. Some topics also contain required courses if elected as a second major subject.

- **Minor**: As a rule, the minor subject in physics consists of a single course on a third topic for at least 8 ECTS credit points, e.g. Semiconductor Physics, Particle Physics I, Theoretical Particle Physics I, etc.

- **Theory/Experiment**: At least one of the major, second major, and minor subjects must belong to the field of experimental physics (Field A) and theoretical physics (Field B), respectively. Some courses of the topics of experimental physics are marked with "(T)"; these are theoretical courses within an otherwise experimental curriculum. Students cannot choose only theoretical courses if they choose only one experimental topic.

Non-Physics Elective

The non-physics elective subject in the area of mathematics, natural or engineering sciences is chosen from the courses offered by KIT departments other than physics. The examination committee publishes a positive list of approved modules and module combinations. Further suitable courses may be approved by the examination committee upon request, these shall include at least six hours a week, four of which must be for lectures. Before taking a non-physics elective that is not on the positive list, students strongly encouraged to consult with the examination committee.

Specialization Phase, Introduction to Scientific Methods, Master Thesis
Students who have successfully passed module examinations in the subjects Major in Physics, Second Major in Physics, Minor in Physics, Advanced Physics Laboratory Course, and Non-Physics Elective can start their specialization phase and register for their Master's thesis.

### Further Rules

- The examiners in the major, second major, minor, and non-physics elective subjects must be different.
- The rules for required courses in the individual topics must be fulfilled separately for the major and the second major subjects.
- All courses offered by the House of Competence (HoC), Zentrum für Angewandte Kulturwissenschaft (ZAK) and the Language Center are approved as part of the subject Interdisciplinary Qualifications. Any other modules must be approved by the examination committee.
- Results reached in the Bachelor's program as part of a non-physics elective subject may not be credited again in the Master's program.

### 1.2.4 Registration for Controls of Success, Subject Examinations, and Master's Thesis

The high flexibility of the Master's program in physics cannot currently be represented in the KIT's student portal "Campus"; therefore, online registration for controls of success and examinations is not possible. Students can register for examinations at the Examination Office (Prüfungssekretariat) of the KIT Department of Physics (Physics High-Rise, Building 30.23, room 9/13) instead. If necessary, successful participation in courses may be confirmed by paper certificates issued by the lecturer.

Since the specialization phase and introduction to scientific methods are carried out under the guidance of the supervisor of the Master's thesis, students register for all three modules before or during the first days of the specialization phase. Registration forms can be obtained from the Examination Office.

### 1.3 Mobility

In the sequence of the Master's program, it is possible to study one semester at a university outside Germany (semester abroad). This semester abroad should be passed before starting work on the Master's thesis. Credits earned abroad will be recognized for the Master's program if they provide comparable competencies to the KIT program. It is recommended to ask the examination committee for the exact conditions of recognition, preferably before starting the courses abroad.

### 1.4 Internships

The Master's program in physics at KIT does not provide for mandatory internships; however, it is possible to complete a voluntary internship. The period suited best for internships is after the second master's semester or after the exams in the major, second major, minor, and non-physics elective subjects and before starting the module "Introduction to Scientific Methods". Students are responsible for finding suitable internships. It is possible to request a semester on leave during the internship.

### 1.5 Graphical Representation of the Plan of Study

<table>
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<tr>
<th>Term</th>
<th>Major in Physics and Master's Thesis</th>
<th>Second Major in Physics</th>
<th>Minor in Physics</th>
<th>Lab Course</th>
<th>Non-Physics Elective</th>
<th>Interdisciplinary Qualifications</th>
<th>CP$^*$</th>
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<td>Modules of the Second Major in Physics</td>
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<td>Advanced Physics Laboratory Course</td>
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<td>3</td>
<td>Specialization Phase</td>
<td>Introduction to Scientific Methods</td>
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<td>4</td>
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Sum: 120
† Credit Points according to the European Credit Transfer and Accumulation System

* Modules of the Minor in Physics, the Advanced Physics Laboratory Course, the Non-Physics Elective and the Interdisciplinary Qualifications are offered both in winter and summer terms and can be taken according to preference. Overload should be avoided.
# Field A: Experimental Physics

## Condensed Matter

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<thead>
<tr>
<th>Courses</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<td>Electronic Properties of Solids I (with/without exercises)</td>
<td>✓ WS</td>
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<td>Ex</td>
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<td>Electronic Properties of Solids II (with/without exercises)</td>
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<td>Physics of Semiconductors (with/without exercises)</td>
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<td>Physics of Solid State Surfaces (with/without exercises)</td>
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<td>✓ WS</td>
<td>L2E1P1/L2</td>
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<td>10 days block practical course</td>
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* This module cannot be combined with an advanced seminar or any non-graded module in the major in physics or second major in physics.

### Major in Physics (Maj):
Required courses are A or C: „Electronic Properties of Solids I“ or „Physics of Semiconductors“.

### Second Major in Physics (Maj2):
Required courses: minimum one out of A, B, C, D, E

### Minor in Physics (Min):
All courses for which the column Min is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with "Ex" in column Min, can only be selected in the variant „with Exercises“.

### Semester Hours:
L: Lecture / E: Exercises / P: Practical Exercises
## 2 Tabular Overview of the Assignment of the Modules

### Nanophysics

<table>
<thead>
<tr>
<th>Courses</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>Semester</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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### Further Courses

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<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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(T) Lecture in Theory – not selectable if „Nanophysics“ is the only experimental subject.
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<tr>
<td>- as well as one course out of C, D, E, F</td>
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## Optics and Photonics

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<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<td>L4</td>
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<td>L2E1</td>
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<td>Semester Hours</td>
<td>ECTS</td>
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<td>Min</td>
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<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures (with/without Exercises and Lab)</td>
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<td>WS</td>
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<td>WS</td>
<td>10 days block practical course</td>
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* This module cannot be combined with an advanced seminar or any non-graded module in the major in physics or second major in physics.

(T) Lecture in Theory– not selectable if „Optics and Photonics“ is the only experimental subject.

### Major in Physics (Maj):
- Required courses are A and B: „Solid-State Optics“ and „Theoretical Optics“

### Second Major in Physics (Maj2):
- At most one course from an external provider („External“)
- At most one course out of the further courses (C-H)

### Minor in Physics (Min):
- All courses for which the column Min is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with “Ex” in column Min, can only be selected in the variant „with Exercises“.

### Semester Hours:
- L: Lecture / E: Exercises / P: Practical Exercises
### Experimental Particle Physics

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<tr>
<td>Measurement Methods and Techniques in Experimental Physics (with/without ext. Exercises) Messmethoden und Techniken der Experimentalphysik (mit/ohne erw. Übungen)</td>
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<td>L2E1P2/L2E1</td>
<td>8/6</td>
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<td>Detectors for Particle and Astroparticle Physics (with/without ext. Exercises) Detektoren für Teilchen- und Astroteilchenphysik (mit/ohne erw. Übungen)</td>
<td>✓ WS</td>
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<td>L2P4/L2P2</td>
<td>6/8</td>
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<tr>
<th>Further Courses</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<td>Particle Physics II – Flavor Physics (with/without ext. Exercises)</td>
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<td>L2E2/L2E1</td>
<td>8/6</td>
<td>F</td>
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<td>Particle Physics II – Top Quarks and Jets at the LHC (with/without ext. Exercises) Teilchenphysik II – Top-Quarks und Jets am LHC (mit/ohne erw. Übungen)</td>
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<td>8/6</td>
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<td>Particle Physics II – Physics Beyond the Standard Model (with/without ext. Exercises) Teilchenphysik ii – Physik jenseits des Standardmodells (mit/ohne erw. Übungen)</td>
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<td>Computational Methods for Particle Physics and Cosmology</td>
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<td>Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training**</td>
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<td>Quantum Detectors and Sensors</td>
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<td>L3E1</td>
<td>8</td>
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* only selectable if „Methods of Data Analysis“ from the field „Meteorology“ is not selected at the same time for the second Major or Minor „Meteorology“
** This module cannot be combined with an advanced seminar or any non-graded module in the major in physics or second major in physics.

(T) Lecture in Theory– not selectable if „Experimental Particle Physics“ is the only experimental subject.

---

**Major in Physics (Maj):**
- Required courses are
  - A („Particle Physics I“)
  - and one from F, G, H, I („Particle Physics II“)

**Second Major (Maj2):**
- Required course is A („Particle Physics I“)

**Minor in Physics (Min):**
- All courses for which the column Min is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with "Ex" in column Min, can only be selected in the variant „with Exercises“.

**Additional Constraints:**
- One can select either C („Electronics for Physicists“) or one out of D or E („Analog Elektronik“ or „Digital Elektronik“) as part of the Major in Physics, Second Major in Physics, or Minor in Physics.

- One can select either B („Modern Methods of Data Analysis“) or J („Computational Methods for Particle Physics and Cosmology“) as part of the Major in Physics or the Second Major in Physics.

**Semester Hours:**
- L: Lecture / E: Exercises / P: Practical Exercises
### Experimental Astroparticle Physics

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<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
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<td>Electronics for Physicists: Digital Electronics</td>
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**Further Courses**

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<th>Maj/ Maj2</th>
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<td>Quantum Detectors and Sensors</td>
<td>WS L3E1</td>
<td>8</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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* only selectable if „Methods of Data Analysis“ from the field „Meteorology“ is not selected at the same time for the second Major or Minor „Meteorology“

** This module cannot be combined with an advanced seminar in the major in physics or second major in physics.

(T) Lecture in Theory– not selectable if „Experimental Particle Physics“ is the only experimental subject.

** Major in Physics (Maj):**

Required courses are
- **A or B**: „Astroparticle Physics I“ or „Introduction to Cosmology“
- **combined with one** course out of **G, H, I**, („Astroparticle Physics II“)

** Second Major in Physics (Maj2):**

Required courses are **A or B**: „Astroparticle Physics I“ or „Introduction to Cosmology“

** Minor in Physics (Min):**

All courses for which the column **Min** is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with "Ex" in column **Min**, can only be selected in the variant „with Exercises“.

**Additonal Constraints:**

One can select **either C** („Electronics for Physics/ics“) or **one out of D or E** („Analog Elektronics“ or „Digital Elektronics“) as part of the Major in Physics, Second Major in Physics, or Minor in Physics.

One can select **either B** („Modern Methods of Data Analysis“) or **J** („Computational Methods for Particle Physics and Cosmology“) as part of the Major in Physics or the Second Major in Physics.

**Semester Hours:**

L: Lecture / E: Exercises / P: Practical Exercises
Field B: Theoretical Physics

Theoretical Particle Physics

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<th>WS 23/24</th>
<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<td>L3E1/L3E2</td>
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<td>Theoretical Particle Physics I, Fundamentals and Advanced Topics (with/without exercises)</td>
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<td>L4E1/L4E2</td>
<td>12/8</td>
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<tr>
<td>Theoretical Particle Physics I, Fundamentals (with/without exercises)</td>
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<td>8/6</td>
<td>B</td>
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<td>Theoretical Particle Physics II (with/without exercises)</td>
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<td>WS</td>
<td>L4E2/L4E3</td>
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<td>Ex</td>
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Further Courses

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<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<td>Introduction to Theoretical Cosmology</td>
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<tr>
<td>Computational Methods for Particle Physics and Cosmology</td>
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<td>Monte Carlo Event Generators</td>
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<td>Mathematical Methods of Theoretical Physics*</td>
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<td>Introduction to Flavor Physics, Fundamentals and Advanced Topics</td>
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<td>Introduction to Flavor Physics, Fundamentals</td>
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<td>Flavour Physics in the Standard Model and beyond</td>
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<td>Particle Physics with Extra Dimensions</td>
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<td>New light Particles beyond the Standard Model (with/without Exercises)</td>
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<td>Symmetries, Groups and extended Gauge Theories</td>
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<td>Classical Theory of Gauge Fields</td>
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<tr>
<td>General Relativity</td>
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<td>General Relativity II</td>
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<tr>
<td>Introduction to General Relativity</td>
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<td>L3E1/L3E2</td>
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<td>Non-supersymmetric Extension of the Standard Model</td>
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<td>Precision Phenomenology at Colliders and Computational Methods (with/without Exercises)</td>
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* Only selectable for the Second Major in Physics if also „Introduction in Theoretical Particle Physics“ or „Theoretical Particle Physics I“ are selected.

Major in Physics (Maj):

Required courses are A or B („Theoretical Particle Physics I“) with 8 or 12 ECTS points

Minor in Physics (Min):

All courses for which the column Min is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with "Ex" in column Min, can only be selected in the variant „with Exercises“.

Semester Hours:

L: Lecture / E: Exercises / P: Practical Exercises
## Condensed Matter Theory

<table>
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<th>Semester Hours</th>
<th>ECTS</th>
<th>Maj/ Maj2</th>
<th>Min</th>
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<tr>
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<tr>
<td>Theorie der kondensierten Materie I, Grundlagen und Vertiefungen</td>
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<tr>
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<tr>
<td>Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics</td>
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<td>Theorie der kondensierten Materie II: Vielteilchentheorie, Grundlagen</td>
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<td>Condensed Matter Theory II: Many-Body Theory, Fundamentals</td>
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<tr>
<td>Condensed Matter Theory II: Many-Body Theory, selected topics*</td>
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<tr>
<td>Theorie der kondensierten Materie II: Vielteilchentheorie, ausgewählte Themen *</td>
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### Further Courses

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<td>L2E1</td>
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<td>Superconductivity, Josephson effect and applications, without/with Exercises</td>
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<td>L3E1/ L3</td>
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<td>Superkondutivitäts Josephson effect und Anwendungen, ohne/mit Übungen</td>
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<td>8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mathematische Methoden der Theoretischen Physik (zweistündig)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of Strongly Correlated Electron Systems</td>
<td></td>
<td>L4E2</td>
<td>12</td>
<td>only Maj</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theorie stark korrelierter Elektronensysteme</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topology in Condensed Matter Physics: Fundamentals and Advanced Topics</td>
<td>✓</td>
<td>L3E1</td>
<td>8</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topology in Condensed Matter Physics: Fundamentals and Selected Topics</td>
<td>✓</td>
<td>L1</td>
<td>2</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Can only be selected as part of the second Major, e.g. to reach 14 ECTS points in combination with „Condensed Matter Theory I, Fundamentals and Advanced Topics“

**Major in Physics (Maj):**
Required courses are **A or B** („Condensed Matter Theory I“) with **8 or 12 ECTS points**

**Minor in Physics (Min):**
All courses for which the column **Min** is marked with ✓, can be selected (as part of) the Minor in Physics. Courses marked with "Ex" in column **Min**, can only be selected in the variant „with Exercises“.

**Semester Hours:**
L: Lecture / E: Exercises / P: Practical Exercises
Field C: Meteorology and Geophysics

Suitable for the **Second Major in Physics (Maj2)** and the **Minor in Physics (Min)**

**Meteorology**

The following courses are part of the Master's program in Meteorology and are offered on an annual basis. Courses below can be combined in the module "Selected Topics in Meteorology (Second Major, graded)" for the Second Major in Physics (14 ECTS credits) and in the module "Selected Topics in Meteorology (Minor, ungraded)" for the Minor in Physics (8 ECTS credits). The criteria for earning the credit points are:

**Minor (ungraded):** The examination is done via a coursework. Whether this is oral, written or of another kind depends on the respective course. Information about this can be found in the guide for all the modules "Master Meteorology and Climate Physics". The credit points are acquired through the individual bricks (8 ECTS points).

**Second Major in Physics (graded):** The examination is done by an oral examination ("Prüfung über meteorologische Spezialgebiete / Exam on Selected Topics in Meteorology"). The prerequisite for admission to the examination is passing the course work. Whether this is oral, written or of another kind depends on the respective course. Information about this can be found in the guide to all the modules „Master Meteorology and Climate Physics“. The credit points are acquired through the individual bricks (at least 10 ECTS points) and the oral examination (4 ECTS points).

<table>
<thead>
<tr>
<th>Courses</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>Semester Hours</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Sensing of Atmosphere and Ocean</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>4</td>
</tr>
<tr>
<td>Turbulent Diffusion</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>4</td>
</tr>
<tr>
<td>Advanced Numerical Weather Prediction</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>4</td>
</tr>
<tr>
<td>Energy Meteorology</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>4</td>
</tr>
<tr>
<td>Methods of Data Analysis*</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>4</td>
</tr>
<tr>
<td>Climate Modeling &amp; Dynamics with ICON</td>
<td>✓ WS</td>
<td>L2E1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Energetics</td>
<td>✓ WS</td>
<td>L2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Cloud Physics</td>
<td>✓ WS</td>
<td>L2E1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Atmospheric Radiation</td>
<td>✓ WS</td>
<td>L2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Atmospheric Aerosols</td>
<td>✓ WS</td>
<td>L2E1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Middle Atmosphere in the Climate System</td>
<td>✓ WS</td>
<td>L2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Tropical Meteorology</td>
<td>✓ WS</td>
<td>L2E1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Seminar on IPCC Assessment Report</td>
<td>✓ WS</td>
<td>S2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ocean-Atmosphere Interactions</td>
<td>✓ WS</td>
<td>L2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Physics of Planetary Atmospheres</td>
<td>✓ WS</td>
<td>L2E2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Arctic Climate System</td>
<td>✓ WS</td>
<td>L2</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

* only selectable if „Modern Methods of Data Analysis“ from the ETP or ATP is not chosen at the same time for the second Major or Minor
Geophysics

Courses in Geophysics can be chosen as ungraded minor in physics (Minor) with a total of 8 ECTS credits or as the graded second major in physics (Maj2) with a total of 14 ECTS credits in the master's program in physics. All courses of the international master program "Geophysics" are held in English.

As a minor subject, individual courses among the compulsory courses in the Master's program "Geophysics" that cover 8 ECTS points are preferably suitable; however, several courses can also be combined if necessary. The examination is done within the framework of course achievements; the type of examination depends on the respective course. More detailed information on the individual courses can be found in the guide to all the modules "Geophysics Master (M.Sc.)."

The following courses are eligible for recognition as a minor in physics. Other courses can be approved by the examination board upon request.

<table>
<thead>
<tr>
<th>Courses suitable as Minor in Physics</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>Semester Hours</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismology</td>
<td>✓</td>
<td>WS</td>
<td>L2E2</td>
<td>8</td>
</tr>
<tr>
<td>Seismologie</td>
<td>✓</td>
<td>WS</td>
<td>L2E2</td>
<td>8</td>
</tr>
<tr>
<td>Seismics</td>
<td></td>
<td>SS</td>
<td>L2E2</td>
<td>6</td>
</tr>
<tr>
<td>Physics of Seismic Instruments</td>
<td></td>
<td>SS</td>
<td>L2E1</td>
<td>6</td>
</tr>
<tr>
<td>Seismic Modelling</td>
<td></td>
<td>SS</td>
<td>L1E1</td>
<td>4</td>
</tr>
<tr>
<td>Full-waveform inversion</td>
<td></td>
<td>L2E1</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

Certain combinations of courses in Geophysics are suitable as second Major in Physics, which, when graded, add up to at least 14 ECTS points. For compulsory courses in the Master's program "Geophysics", i.e. the courses "Physics of Seismic Instruments", "Seismology" and "Seismics" in the winter semester and "Inversion and Tomography", "Theory of Seismic Waves" and "Seismic Modelling" in the summer semester, the examination is done by an oral examination for the respective semester. Students who choose Geophysics as a second major in physics are admitted to the oral examination if they pass the relevant course work(s). The way in which individual course achievements are assessed depends on the course in question. More detailed information on the individual courses can be found in the guide to all the modules "Geophysics Master (M.Sc.)." For students who choose Geophysics as the second Major in Physics, the examination material of the oral comprehensive examination covers only the respective course achievement(s) passed, not all three course achievements that are part of the respective module, as is the case for students of Geophysics. In the case of graded elective courses in the Master's program "Geophysics", the type of performance assessment and grading depends on the respective course; again, see the guide to all the modules "Geophysics Master (M.Sc.)" for details. The grades of the second Major in Physics are included in the overall grade of the master's examination as described in the section "Grade formation".

<table>
<thead>
<tr>
<th>Course</th>
<th>WS 23/24</th>
<th>Reg.</th>
<th>WS</th>
<th>SS</th>
<th>WS</th>
<th>SS</th>
<th>SS</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismology (v2u2)</td>
<td>✓</td>
<td>WS</td>
<td>16 LP</td>
<td>16 LP</td>
<td>14 LP</td>
<td>14 LP</td>
<td>16 LP</td>
<td>16 LP</td>
</tr>
<tr>
<td>Seismics (v2u2)</td>
<td>✓</td>
<td>WS</td>
<td>16 LP</td>
<td>16 LP</td>
<td>14 LP</td>
<td>14 LP</td>
<td>16 LP</td>
<td>14 LP</td>
</tr>
<tr>
<td>Inversion and Tomography (v2u2)</td>
<td></td>
<td>SS</td>
<td>16 LP</td>
<td>16 LP</td>
<td>14 LP</td>
<td>14 LP</td>
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</table>
## 3 Field of study structure

<table>
<thead>
<tr>
<th>Mandatory</th>
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<tbody>
<tr>
<td>Master's Thesis</td>
<td>30 CR</td>
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<tr>
<td>Major in Physics (Election: 1 item)</td>
<td></td>
</tr>
<tr>
<td>Major in Physics: Condensed Matter</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Nanophysics</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Optics and Photonics</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Experimental Particle Physics</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Experimental Astroparticle Physics</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Theoretical Particle Physics</td>
<td>20 CR</td>
</tr>
<tr>
<td>Major in Physics: Condensed Matter Theory</td>
<td>20 CR</td>
</tr>
<tr>
<td>Second Major in Physics (Election: 1 item)</td>
<td></td>
</tr>
<tr>
<td>Second Major in Physics: Condensed Matter</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Nanophysics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Optics and Photonics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Experimental Particle Physics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Experimental Astroparticle Physics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Theoretical Particle Physics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Condensed Matter Theory</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Geophysics</td>
<td>14 CR</td>
</tr>
<tr>
<td>Second Major in Physics: Meteorology</td>
<td>14 CR</td>
</tr>
<tr>
<td>Minor in Physics (Election: 1 item)</td>
<td></td>
</tr>
<tr>
<td>Minor in Physics: Condensed Matter</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Nanophysics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Optics and Photonics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Experimental Particle Physics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Experimental Astroparticle Physics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Theoretical Particle Physics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Condensed Matter Theory</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Geophysics</td>
<td>8 CR</td>
</tr>
<tr>
<td>Minor in Physics: Meteorology</td>
<td>8 CR</td>
</tr>
<tr>
<td>Mandatory Elective</td>
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</tr>
<tr>
<td>Non-Physics Elective</td>
<td>8 CR</td>
</tr>
<tr>
<td>Advanced Physics Laboratory Course</td>
<td>6 CR</td>
</tr>
<tr>
<td>Specialization Phase</td>
<td>15 CR</td>
</tr>
<tr>
<td>Introduction to Scientific Methods</td>
<td>15 CR</td>
</tr>
<tr>
<td>Interdisciplinary Qualifications</td>
<td>4 CR</td>
</tr>
<tr>
<td>Voluntary</td>
<td></td>
</tr>
<tr>
<td>Additional Examinations</td>
<td></td>
</tr>
<tr>
<td>This field will not influence the calculated grade of its parent.</td>
<td></td>
</tr>
</tbody>
</table>
### 3.1 Master’s Thesis

<table>
<thead>
<tr>
<th>Mandatory</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-106481 Master’s Thesis</td>
<td>30 CR</td>
</tr>
</tbody>
</table>

### 3.2 Major in Physics: Condensed Matter

<table>
<thead>
<tr>
<th>Required Condensed Matter (Election: between 1 and 2 items)</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-102089 Electronic Properties of Solids I, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-102090 Electronic Properties of Solids I, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102131 Physics of Semiconductors, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-102301 Physics of Semiconductors, without Exercises</td>
<td>8 CR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elective Condensed Matter (Election: )</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-102109 Electronic Properties of Solids II, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102108 Electronic Properties of Solids II, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102990 Electron Microscopy I, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102989 Electron Microscopy I, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-106483 Surface Science, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-106482 Surface Science, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-105537 Solid State Quantum Computing</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-105871 Solid State Quantum Computing, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102408 Solid-State Optics</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102191 Superconducting Nanostructures</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-102844 Electron Microscopy II, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102227 Electron Microscopy II, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-104871 Accelerator Physics, without ext. Exercises</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-104869 Accelerator Physics, with ext. Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102293 Spin Transport in Nanostructures</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-104857 Solid State Quantum Technologies</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-105071 Nanomaterials, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-105068 Nanomaterials, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-105556 X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-105555 X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-104540 Molecular Electronics</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-106323 Introduction to Neutron Scattering</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-102203 Advanced Seminar in the Area Condensed Matter</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-106399 Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training</td>
<td>4 CR</td>
</tr>
</tbody>
</table>
### Major in Physics: Nanophysics

**Credits**

**20**

<table>
<thead>
<tr>
<th><strong>Mandatory</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-102097 Basics of Nanotechnology I</td>
<td>4 CR</td>
<td></td>
</tr>
<tr>
<td>M-PHYS-102100 Basics of Nanotechnology II</td>
<td>4 CR</td>
<td></td>
</tr>
</tbody>
</table>

**Required Elective Nanophysics (Election: at least 1 item)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-102089</td>
<td>Electronic Properties of Solids I, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-102090</td>
<td>Electronic Properties of Solids I, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-106482</td>
<td>Surface Science, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-106483</td>
<td>Surface Science, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102131</td>
<td>Physics of Semiconductors, with Exercises</td>
<td>10 CR</td>
</tr>
<tr>
<td>M-PHYS-102301</td>
<td>Physics of Semiconductors, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102165</td>
<td>Experimental Biophysics II, with Seminar</td>
<td>14 CR</td>
</tr>
<tr>
<td>M-PHYS-102167</td>
<td>Experimental Biophysics II, without Seminar</td>
<td>12 CR</td>
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</table>

**Elective Nanophysics (Election: )**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-PHYS-102108</td>
<td>Electronic Properties of Solids II, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102109</td>
<td>Electronic Properties of Solids II, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102990</td>
<td>Electron Microscopy I, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102989</td>
<td>Electron Microscopy I, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102146</td>
<td>Nano-Optics</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102227</td>
<td>Electron Microscopy II, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102844</td>
<td>Electron Microscopy II, without Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-105555</td>
<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-105556</td>
<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-102191</td>
<td>Superconducting Nanostructures</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-105071</td>
<td>Nanomaterials, without Exercises</td>
<td>4 CR</td>
</tr>
<tr>
<td>M-PHYS-105068</td>
<td>Nanomaterials, with Exercises</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102171</td>
<td>Theoretical Molecular Biophysics, without Seminar</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-102169</td>
<td>Theoretical Molecular Biophysics, with Seminar</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-102277</td>
<td>Theoretical Optics</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-102295</td>
<td>Theoretical Nanooptics</td>
<td>6 CR</td>
</tr>
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<td>Spin Transport in Nanostructures</td>
<td>6 CR</td>
</tr>
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<td>Computational Photonics, with ext. Exercises</td>
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<td>Microscale Fluid Mechanics</td>
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### Major in Physics: Optics and Photonics

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<td>Nonlinear Optics</td>
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<td>Photovoltaics</td>
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<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab</td>
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### 3.5 Major in Physics: Experimental Particle Physics

#### Mandatory

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#### Required Elective Experimental Particle Physics (Election: at least 1 item)

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<td>M-PHYS-102154</td>
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<td>M-PHYS-104081</td>
<td>Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises</td>
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<td>Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises</td>
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<td>M-PHYS-104086</td>
<td>Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises</td>
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<td>Electronics for Physicists: Analog Electronics</td>
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<td>M-PHYS-102518</td>
<td>Measurement Methods and Techniques in Experimental Physics, without ext. Exercises</td>
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<td>M-PHYS-102119</td>
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<td>M-PHYS-106047</td>
<td>Modern Methods of Spectroscopy: Applications in Astroparticle Physics</td>
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<td>Computational Methods for Particle Physics and Cosmology</td>
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### 3.6 Major in Physics: Experimental Astroparticle Physics

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**Further Required Experimental Astroparticle Physics (Election: at least 1 item)**

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<td>M-PHYS-102078</td>
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<td>M-PHYS-105683</td>
<td>Astroparticle Physics II - Gamma Rays and Neutrinos</td>
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<td>M-PHYS-102527</td>
<td>Astroparticle Physics II - Particles and Stars, with ext. Exercises</td>
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<td>M-PHYS-102081</td>
<td>Astroparticle Physics II - Particles and Stars, without ext. Exercises</td>
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**Elective Experimental Astroparticle Physics (Election: )**

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<td>Electronics for Physicists: Digital Electronics</td>
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<td>Measurement Methods and Techniques in Experimental Physics, with ext. Exercises</td>
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# 3 Major in Physics: Theoretical Particle Physics

**Credits**: 20

## Required Theoretical Particle Physics (Election: 1 item)

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## Elective Theoretical Particle Physics (Election: )

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<td>Introduction to Theoretical Cosmology</td>
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<td>Symmetries and Groups</td>
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<td>Classical Theory of Gauge Fields</td>
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### 3.8 Major in Physics: Condensed Matter Theory

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<td>M-PHYS-102308</td>
<td>Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics</td>
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<td>Field Theories of Condensed Matter: Conformal Field Theory</td>
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<td>Theoretical Nanooptics</td>
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### 3.9 Second Major in Physics: Condensed Matter

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<td>M-PHYS-102090 Electronic Properties of Solids I, without Exercises</td>
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<td>M-PHYS-102301 Physics of Semiconductors, without Exercises</td>
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<td>M-PHYS-102408 Solid-State Optics</td>
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<th>Elective Condensed Matter (Election: )</th>
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<td>M-PHYS-102989 Electron Microscopy I, with Exercises</td>
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<tr>
<td>M-PHYS-102227 Electron Microscopy II, with Exercises</td>
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<td>M-PHYS-102844 Electron Microscopy II, without Exercises</td>
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<td>M-PHYS-104871 Accelerator Physics, without ext. Exercises</td>
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<tr>
<td>M-PHYS-102293 Spin Transport in Nanostructures</td>
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<tr>
<td>M-PHYS-104857 Solid State Quantum Technologies</td>
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<tr>
<td>M-PHYS-105068 Nanomaterials, with Exercises</td>
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<td>M-PHYS-105071 Nanomaterials, without Exercises</td>
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<tr>
<td>M-PHYS-105555 X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab</td>
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<td>M-PHYS-105556 X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab</td>
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## 3.10 Second Major in Physics: Nanophysics

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<td>M-PHYS-102100 Basics of Nanotechnology II</td>
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<tr>
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<td>M-PHYS-102090 Electronic Properties of Solids I, without Exercises</td>
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<td>M-PHYS-102109 Electronic Properties of Solids II, without Exercises</td>
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<td>M-PHYS-102131 Physics of Semiconductors, with Exercises</td>
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<td>M-PHYS-1022301 Physics of Semiconductors, without Exercises</td>
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<td>M-PHYS-106482 Surface Science, with Exercises</td>
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<td>M-PHYS-106483 Surface Science, without Exercises</td>
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<td>M-PHYS-102167 Experimental Biophysics II, without Seminar</td>
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<td>M-PHYS-102165 Experimental Biophysics II, with Seminar</td>
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<td>M-PHYS-102191 Superconducting Nanostructures</td>
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<td>M-PHYS-102169 Theoretical Molecular Biophysics, with Seminar</td>
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<td>M-PHYS-101933 Computational Photonics, with ext. Exercises</td>
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<td>M-PHYS-103089 Computational Photonics, without ext. Exercises</td>
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<td>M-PHYS-104862 Computational Condensed Matter Physics</td>
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<td>M-PHYS-102204 Advanced Seminar in the Area Nanophysics</td>
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<td>M-PHYS-106508 Quantum Optics at the Nano Scale, with Exercises</td>
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<td>M-PHYS-106510 Quantum Optics at the Nano Scale, without Exercises</td>
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<tr>
<td>M-MACH-106539 Microscale Fluid Mechanics</td>
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## Elective Optics and Photonics (Election: at least 14 credits)

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<td>M-PHYS-102146</td>
<td>Nano-Optics</td>
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<td>M-PHYS-102277</td>
<td>Theoretical Optics</td>
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<td>Theoretical Nanooptics</td>
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<td>M-PHYS-102337</td>
<td>Molecular Spectroscopy</td>
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<td>M-ETIT-100430</td>
<td>Nonlinear Optics</td>
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<td>M-ETIT-100513</td>
<td>Photovoltaics</td>
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<td>M-PHYS-105555</td>
<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab</td>
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<td>M-PHYS-105556</td>
<td>X-ray Physics I: Scattering, Diffraction &amp; Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab</td>
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<td>M-PHYS-105558</td>
<td>X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab</td>
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<td>M-PHYS-105559</td>
<td>X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, without Exercises and without Lab</td>
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<td>M-PHYS-102167</td>
<td>Experimental Biophysics II, without Seminar</td>
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<td>M-PHYS-105094</td>
<td>Theoretical Quantum Optics</td>
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<td>M-PHYS-101933</td>
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### 3.12 Second Major in Physics: Experimental Particle Physics

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<td><strong>M-Phys-102125</strong></td>
<td>Modern Methods of Data Analysis, without ext. Exercises</td>
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<td><strong>M-Phys-102174</strong></td>
<td>Electronics for Physicists</td>
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<td><strong>M-Phys-102192</strong></td>
<td>Electronics for Physicists: Analog Electronics</td>
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<td>Accelerator Physics, with ext. Exercises</td>
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<td><strong>M-Phys-104871</strong></td>
<td>Accelerator Physics, without ext. Exercises</td>
<td>6 CR</td>
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<tr>
<td><strong>M-Phys-102517</strong></td>
<td>Measurement Methods and Techniques in Experimental Physics, with ext. Exercises</td>
<td>8 CR</td>
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<tr>
<td><strong>M-Phys-102518</strong></td>
<td>Measurement Methods and Techniques in Experimental Physics, without ext. Exercises</td>
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<tr>
<td><strong>M-Phys-102193</strong></td>
<td>Detectors for Particle and Astroparticle Physics, with ext. Exercises</td>
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<tr>
<td><strong>M-Phys-102194</strong></td>
<td>Detectors for Particle and Astroparticle Physics, without ext. Exercises</td>
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<td><strong>M-Phys-102471</strong></td>
<td>Particle Physics II - Flavour Physics, with ext. Exercises</td>
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<td><strong>M-Phys-102472</strong></td>
<td>Particle Physics II - Flavour Physics, without ext. Exercises</td>
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<td><strong>M-Phys-104081</strong></td>
<td>Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises</td>
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<td><strong>M-Phys-104083</strong></td>
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<td><strong>M-Phys-104087</strong></td>
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<td><strong>M-Phys-105937</strong></td>
<td>Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises</td>
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<td><strong>M-Phys-105938</strong></td>
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<tr>
<td><strong>M-Phys-106047</strong></td>
<td>Modern Methods of Spectroscopy: Applications in Astroparticle Physics</td>
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<td><strong>M-Phys-106117</strong></td>
<td>Computational Methods for Particle Physics and Cosmology</td>
<td>6 CR</td>
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<td><strong>M-Phys-105939</strong></td>
<td>Quantum Detectors and Sensors</td>
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<td><strong>M-Phys-105940</strong></td>
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<td><strong>M-Phys-106530</strong></td>
<td>Block Practical Course: ETP Data Science</td>
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### 3.13 Second Major in Physics: Experimental Astroparticle Physics

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<td>M-PHYS-102075 Astroparticle Physics I</td>
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<td>M-PHYS-102175 Introduction to Cosmology</td>
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<tr>
<td>M-PHYS-105683 Astroparticle Physics II - Gamma Rays and Neutrinos</td>
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<td>M-PHYS-102527 Astroparticle Physics II - Particles and Stars, with ext. Exercises</td>
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<tr>
<td>M-PHYS-102081 Astroparticle Physics II - Particles and Stars, without ext. Exercises</td>
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<td>M-PHYS-102127 Modern Methods of Data Analysis, with ext. Exercises</td>
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<td>M-PHYS-102125 Modern Methods of Data Analysis, without ext. Exercises</td>
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<td>M-PHYS-102184 Electronics for Physicists</td>
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<td>M-PHYS-102121 Detectors for Particle and Astroparticle Physics, with ext. Exercises</td>
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<td>M-PHYS-102119 Detectors for Particle and Astroparticle Physics, without ext. Exercises</td>
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<td>M-PHYS-102319 General Relativity</td>
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<td>M-PHYS-106047 Modern Methods of Spectroscopy: Applications in Astroparticle Physics</td>
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<td>M-PHYS-106117 Computational Methods for Particle Physics and Cosmology</td>
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<td>M-PHYS-106532 Introduction to General Relativity</td>
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<tr>
<td>M-PHYS-106530 Block Practical Course: ETP Data Science</td>
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### 3.14 Second Major in Physics: Theoretical Particle Physics

**Elective Theoretical Particle Physics (Election: at least 14 credits)**

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<td>Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises</td>
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<td>M-PHYS-102035</td>
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<td>M-PHYS-102034</td>
<td>Theoretical Particle Physics I, Fundamentals, with Exercises</td>
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<td>M-PHYS-104860</td>
<td>Monte Carlo Event Generators</td>
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<td>M-PHYS-105834</td>
<td>Mathematical Methods of Theoretical Physics (two hours per week)</td>
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<tr>
<td>M-PHYS-102986</td>
<td>Introduction to Flavor Physics, Fundamentals and Advanced Topics</td>
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<td>M-PHYS-102987</td>
<td>Introduction to Flavor Physics, Fundamentals</td>
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<td>Flavour Physics in the Standard Model and beyond</td>
<td>4 CR</td>
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<td>New Light Particles Beyond the Standard Model</td>
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# Second Major in Physics: Condensed Matter Theory

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# Second Major in Physics: Geophysics

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<td>Geological Hazards and Risk</td>
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# Second Major in Physics: Meteorology

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### Minor in Physics: Condensed Matter

#### Elective Condensed Matter (Election: at least 8 credits)

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<td>M-PHYS-102130</td>
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<td>Nanomaterials, with Exercises (Minor)</td>
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Physics Master (Master of Science)  
Module Handbook as of 20/09/2023
### 3.19 Minor in Physics: Nanophysics

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### Minor in Physics: Optics and Photonics

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<td>Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training</td>
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### 3.21 Minor in Physics: Experimental Particle Physics

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<td>M-PHYS-102180</td>
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<td>6 CR</td>
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<tr>
<td>M-PHYS-102183</td>
<td>Electronics for Physicists: Digital Electronics (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-104870</td>
<td>Accelerator Physics, with ext. exercises (Minor)</td>
<td>8 CR</td>
</tr>
<tr>
<td>M-PHYS-104872</td>
<td>Accelerator Physics, without ext. exercises (Minor)</td>
<td>6 CR</td>
</tr>
<tr>
<td>M-PHYS-102519</td>
<td>Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-103194</td>
<td>Measurement Methods and Techniques in Experimental Physics, without ext. Exercises (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-102122</td>
<td>Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102120</td>
<td>Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-103184</td>
<td>Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102082</td>
<td>Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-105684</td>
<td>Astroparticle Physics II - Gamma Rays and Neutrinos (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-105685</td>
<td>Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-103186</td>
<td>Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor)</td>
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<tr>
<td>M-PHYS-102086</td>
<td>Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor)</td>
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<tr>
<td>M-PHYS-102320</td>
<td>General Relativity (Minor)</td>
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<tr>
<td>M-PHYS-106118</td>
<td>Computational Methods for Particle Physics and Cosmology (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-106047</td>
<td>Modern Methods of Spectroscopy: Applications in Astroparticle Physics</td>
<td>2 CR</td>
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<td>M-PHYS-106194</td>
<td>Quantum Detectors and Sensors (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102207</td>
<td>Advanced Seminar in the Area Experimental Astroparticle Physics</td>
<td>4 CR</td>
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<tr>
<td>M-PHYS-106533</td>
<td>Introduction to General Relativity (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-106530</td>
<td>Block Practical Course: ETP Data Science</td>
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### 3.23 Minor in Physics: Theoretical Particle Physics

Elective Theoretical Particle Physics (Election: at least 8 credits)

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<td>M-PHYS-102424</td>
<td>Introduction to Theoretical Particle Physics, with ext. Exercises (Minor)</td>
<td>10 CR</td>
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<td>M-PHYS-102426</td>
<td>Introduction to Theoretical Particle Physics, without ext. Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102037</td>
<td>Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor)</td>
<td>12 CR</td>
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<tr>
<td>M-PHYS-102038</td>
<td>Theoretical Particle Physics I, Fundamentals, with Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102044</td>
<td>Theoretical Particle Physics II, with Exercises (Minor)</td>
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<td>M-PHYS-104856</td>
<td>Introduction to Theoretical Cosmology (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-106118</td>
<td>Computational Methods for Particle Physics and Cosmology (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-104861</td>
<td>Monte Carlo Event Generators (Minor)</td>
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<tr>
<td>M-PHYS-105835</td>
<td>Mathematical Methods of Theoretical Physics (two hours per week) (Minor)</td>
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<tr>
<td>M-PHYS-103188</td>
<td>Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor)</td>
<td>12 CR</td>
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<td>M-PHYS-103189</td>
<td>Introduction to Flavor Physics, Fundamentals (Minor)</td>
<td>10 CR</td>
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<tr>
<td>M-PHYS-105582</td>
<td>New Light Particles Beyond the Standard Model (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102316</td>
<td>Symmetries, Groups and Extended Gauge Theories (Minor)</td>
<td>12 CR</td>
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<tr>
<td>M-PHYS-102318</td>
<td>Symmetries and Groups (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102320</td>
<td>General Relativity (Minor)</td>
<td>10 CR</td>
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<tr>
<td>M-PHYS-103334</td>
<td>General Relativity II (Minor)</td>
<td>10 CR</td>
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<tr>
<td>M-PHYS-105639</td>
<td>Non-supersymmetric Extensions of the Standard Model (Minor)</td>
<td>4 CR</td>
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<tr>
<td>M-PHYS-105642</td>
<td>Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102208</td>
<td>Advanced Seminar in the Area Theoretical Particle Physics</td>
<td>4 CR</td>
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<tr>
<td>M-PHYS-106533</td>
<td>Introduction to General Relativity (Minor)</td>
<td>8 CR</td>
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### 3.24 Minor in Physics: Condensed Matter Theory

Elective Condensed Matter Theory (Election: at least 1 item as well as at least 8 credits)

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<td>M-PHYS-102051</td>
<td>Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor)</td>
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<tr>
<td>M-PHYS-102052</td>
<td>Condensed Matter Theory I, Fundamentals (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-102312</td>
<td>Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor)</td>
<td>12 CR</td>
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<tr>
<td>M-PHYS-102314</td>
<td>Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-105943</td>
<td>Theory and Applications of Quantum Machines (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-104863</td>
<td>Computational Condensed Matter Physics (Minor)</td>
<td>12 CR</td>
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<tr>
<td>M-PHYS-102172</td>
<td>Theoretical Molecular Biophysics, without Seminar (Minor)</td>
<td>6 CR</td>
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<tr>
<td>M-PHYS-102170</td>
<td>Theoretical Molecular Biophysics, with Seminar (Minor)</td>
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<tr>
<td>M-PHYS-103177</td>
<td>Theoretical Nanooptics (Minor)</td>
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<td>M-PHYS-105656</td>
<td>Superconductivity, Josephson Effect and Applications, with Exercises (Minor)</td>
<td>8 CR</td>
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<td>M-PHYS-105385</td>
<td>Theory of Magnetism, with Exercises (Minor)</td>
<td>8 CR</td>
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<tr>
<td>M-PHYS-105395</td>
<td>Theoretical Quantum Optics (Minor)</td>
<td>6 CR</td>
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<td>M-PHYS-102209</td>
<td>Advanced Seminar in the Area Condensed Matter Theory</td>
<td>4 CR</td>
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<td>M-PHYS-106587</td>
<td>Topology in Condensed Matter Physics: Fundamentals and Advanced Topics (Minor)</td>
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### 3.25 Minor in Physics: Geophysics

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<tr>
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<td>Elective Geophysics (Election: at least 8 credits)</td>
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<td>8</td>
<td>Seismology (Minor)</td>
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<td>8</td>
<td>Seisms (Minor)</td>
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<td>6</td>
<td>Physics of Seismic Instruments (Minor)</td>
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<td>8</td>
<td>Inversion and Tomography (Minor)</td>
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<td>6</td>
<td>Theory of Seismic Waves (Minor)</td>
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<td>4</td>
<td>Seismic Modeling (Minor)</td>
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<td>6</td>
<td>Full-Waveform Inversion (Ungraded)</td>
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### 3.26 Minor in Physics: Meteorology

<table>
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<th>Credit Hours</th>
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<tr>
<td>8</td>
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<td>Selected Topics in Meteorology (Minor, ungraded)</td>
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### 3.27 Non-Physics Elective

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<tr>
<td>8</td>
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<td>10</td>
<td>Electronics for Physicists</td>
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<td>8</td>
<td>Wildcard Non-Physics Elective, Module with 1 Brick</td>
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<td>8</td>
<td>Wildcard Non-Physics Elective, Module with 2 Bricks</td>
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<td>8</td>
<td>Wildcard Non-Physics Elective, Module with 3 Bricks</td>
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### 3.28 Advanced Physics Laboratory Course

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<th>Credit Hours</th>
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### 3.29 Specialization Phase

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### 3.30 Introduction to Scientific Methods

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<th>Credit Hours</th>
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### 3.31 Interdisciplinary Qualifications

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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>M-PHYS-101394</td>
<td>Interdisciplinary Qualifications</td>
<td>4 CR</td>
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### 3.32 Additional Examinations

Additional Examinations (Election: at most 30 credits)

<table>
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<tr>
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<tr>
<td>M-ZAK-106099</td>
<td>Supplementary Studies on Sustainable Development</td>
<td>19 CR</td>
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<tr>
<td>M-ZAK-106235</td>
<td>Supplementary Studies on Culture and Society</td>
<td>22 CR</td>
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</table>
4 Modules

4.1 Module: Accelerator Physics, with ext. Exercises [M-PHYS-104869]

| Responsible: | Dr. Axel Bernhard                  |
|             | Prof. Dr. Anke-Susanne Müller     |
| Organisation: | KIT Department of Physics         |
| Part of:     | Major in Physics: Condensed Matter (Elective Condensed Matter) |
|             | Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics) |
|             | Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics) |
|             | Second Major in Physics: Condensed Matter (Elective Condensed Matter) |
|             | Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics) |
|             | Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics) |

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<tr>
<td>Duration</td>
<td>1 term</td>
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<td>Language</td>
<td>English</td>
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<td>Level</td>
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<tr>
<td>Version</td>
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Mandatory

T-PHYS-109904  Accelerator Physics, with ext. Exercises  8 CR  Bernhard, Müller

Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites

none

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-104870 - Accelerator Physics, with ext. exercises (Minor) must not have been started.
2. The module M-PHYS-104871 - Accelerator Physics, without ext. Exercises must not have been started.
3. The module M-PHYS-104872 - Accelerator Physics, without ext. exercises (Minor) must not have been started.

Competence Goal

After attending the course, you will be able to present the basics of accelerator physics and calculate simple beam transport systems. You will be able to describe the basic accelerator types, compare their modes of operation and assess their suitability for use in physics experiments. You will be able to present the essential properties of synchrotron radiation, describe the physical principles as well as the most important technical concepts for its generation and calculate essential characteristics of a synchrotron radiation source. On this basis, you will be able to conceptually design radiation sources to given experimental requirements. You will be able to describe accelerator-relevant technologies and to identify, classify and justify the various methods for measuring and controlling beam parameters. Your acquired knowledge of the interaction of ensembles of particles with each other and with the radiation they produce will enable you to provide a sound description of the operation of the free-electron laser and to establish overall criteria for the optimization of accelerators for a given application. In the extended exercises you will deepen the learned material by means of selected practical examples and applications.

Content

- Basic types of accelerators (including electrostatic accelerators, linacs, circular accelerators, storage rings & colliders).
- Physics of synchrotron radiation, wigglers and undulators (electrodynamics of moving point charges, properties of normal synchrotron radiation and undulator radiation)
- Beam optics and beam dynamics (e.g., magnetic lenses, beam properties, transverse & longitudinal oscillation and damping, many-particle systems)
- Magnetic technology for accelerators and synchrotron radiation sources
- Measurement and control of beam parameters
- Free-electron laser
- Performance limits of accelerators (e.g., ultra-short electron pulses, high-intensity proton beams, beam-beam interactions in colliders)
- New technologies, current & future projects
Workload
240 hours consisting of attendance time (60 hours), preparation and wrap-up of the lecture, the integrated exercises and exam preparation (120 hours), preparation and execution of the practical exercises, evaluations and preparation of measurement protocols (60 hours).

Literature
- E.J.N. Wilson: An Introduction to Particle Accelerators, Oxford University Press, 2001
- H. Wiedemann: Particle Accelerator Physics 1 & 2, Springer, 1993
4.2 Module: Accelerator Physics, with ext. exercises (Minor) [M-PHYS-104870]

<table>
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<td>Each winter term</td>
<td>1 term</td>
<td>English</td>
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**Mandatory**

| T-PHYS-109903 | Accelerator Physics, with ext. exercises (Minor) | 8 CR | Bernhard, Müller |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104869 - Accelerator Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-104871 - Accelerator Physics, without ext. Exercises must not have been started.
3. The module M-PHYS-104872 - Accelerator Physics, without ext. exercises (Minor) must not have been started.

**Competence Goal**
After attending the course, you will be able to present the basics of accelerator physics and calculate simple beam transport systems. You will be able to describe the basic accelerator types, compare their modes of operation and assess their suitability for use in physics experiments. You will be able to present the essential properties of synchrotron radiation, describe the physical principles as well as the most important technical concepts for its generation and calculate essential characteristics of a synchrotron radiation source. On this basis, you will be able to conceptually design radiation sources to given experimental requirements. You will be able to describe accelerator-relevant technologies and to identify, classify and justify the various methods for measuring and controlling beam parameters. Your acquired knowledge of the interaction of ensembles of particles with each other and with the radiation they produce will enable you to provide a sound description of the operation of the free-electron laser and to establish overall criteria for the optimization of accelerators for a given application. In the extended exercises you will deepen the learned material by means of selected practical examples and applications.

**Content**

- Basic types of accelerators (including electrostatic accelerators, linacs, circular accelerators, storage rings & colliders).
- Physics of synchrotron radiation, wigglers and undulators (electrodynamics of moving point charges, properties of normal synchrotron radiation and undulator radiation)
- Beam optics and beam dynamics (e.g., magnetic lenses, beam properties, transverse & longitudinal oscillation and damping, many-particle systems)
- Magnetic technology for accelerators and synchrotron radiation sources
- Measurement and control of beam parameters
- Free-electron laser
- Performance limits of accelerators (e.g., ultra-short electron pulses, high-intensity proton beams, beam-beam interactions in colliders)
- New technologies, current & future projects

**Workload**
240 hours consisting of attendance time (60 hours), preparation and wrap-up of the lecture, the integrated exercises (120 hours), preparation and execution of the practical exercises, evaluations and preparation of measurement protocols (60 hours).
Literature

- E.J.N. Wilson: An Introduction to Particle Accelerators, Oxford University Press, 2001
- H. Wiedemann: Particle Accelerator Physics 1&2, Springer, 1993
4.3 Module: Accelerator Physics, without ext. Exercises [M-PHYS-104871]

**Responsible:** Dr. Axel Bernhard
Prof. Dr. Anke-Susanne Müller

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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<th>Grading scale</th>
<th>Recurrence</th>
<th>Duration</th>
<th>Language</th>
<th>Level</th>
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<td>Each winter term</td>
<td>1 term</td>
<td>English</td>
<td>4</td>
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</table>

**Mandatory**

| T-PHYS-109905 | Accelerator Physics, without ext. Exercises | 6 CR | Bernhard, Müller |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104869 - Accelerator Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-104870 - Accelerator Physics, with ext. exercises (Minor) must not have been started.
3. The module M-PHYS-104872 - Accelerator Physics, without ext. exercises (Minor) must not have been started.

**Competence Goal**

After attending the course, you will be able to present the basics of accelerator physics and calculate simple beam transport systems. You will be able to describe the basic accelerator types, compare their modes of operation and assess their suitability for use in physics experiments. You will be able to present the essential properties of synchrotron radiation, describe the physical principles as well as the most important technical concepts for its generation and calculate essential characteristics of a synchrotron radiation source. On this basis, you will be able to conceptually design radiation sources to given experimental requirements. You will be able to describe accelerator-relevant technologies and to identify, classify and justify the various methods for measuring and controlling beam parameters. Your acquired knowledge of the interaction of particle ensembles with each other and with the radiation they produce will enable you to describe the operation of the free-electron laser in a well-founded manner and to establish overall criteria for the optimization of accelerators for a given application.

**Content**

- Basic types of accelerators (including electrostatic accelerators, linacs, circular accelerators, storage rings & colliders).
- Physics of synchrotron radiation, wigglers and undulators (electrodynamics of moving point charges, properties of normal synchrotron radiation and undulator radiation).
- Beam optics and beam dynamics (e.g., magnetic lenses, beam properties, transverse & longitudinal oscillation and damping, many-particle systems).
- Magnetic technology for accelerators and synchrotron radiation sources.
- Measurement and control of beam parameters.
- Free-electron laser.
- Performance limits of accelerators (e.g., ultra-short electron pulses, high-intensity proton beams, beam-beam interactions in colliders).
- New technologies, current & future projects.
Workload
180 hours consisting of attendance time (60 hours), preparation and wrap-up of the lecture, the integrated exercises and exam preparation (120 hours).

Literature
- E.J.N. Wilson: An Introduction to Particle Accelerators, Oxford University Press, 2001
- H. Wiedemann: Particle Acclerator Physics 1&2, Springer, 1993
4.4 Module: Accelerator Physics, without ext. exercises (Minor) [M-PHYS-104872]

**Responsible:** Dr. Axel Bernhard
Prof. Dr. Anke-Susanne Müller

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Experimental Particle Physics
- Minor in Physics: Experimental Astroparticle Physics

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<th>Duration</th>
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**Mandatory**

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<tbody>
<tr>
<td>T-PHYS-109906</td>
<td>Accelerator Physics, without ext. exercises (Minor)</td>
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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104869 - Accelerator Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-104870 - Accelerator Physics, with ext. exercises (Minor) must not have been started.
3. The module M-PHYS-104871 - Accelerator Physics, without ext. Exercises must not have been started.

**Competence Goal**
After attending the course, you will be able to present the basics of accelerator physics and calculate simple beam transport systems. You will be able to describe the basic accelerator types, compare their modes of operation and assess their suitability for use in physics experiments. You will be able to present the essential properties of synchrotron radiation, describe the physical principles as well as the most important technical concepts for its generation and calculate essential characteristics of a synchrotron radiation source. On this basis, you will be able to conceptually design radiation sources to given experimental requirements. You will be able to describe accelerator-relevant technologies and to identify, classify and justify the various methods for measuring and controlling beam parameters. Your acquired knowledge of the interaction of particle ensembles with each other and with the radiation they produce will enable you to describe the operation of the free-electron laser in a well-founded manner and to establish overall criteria for the optimization of accelerators for a given application.

**Content**

- Basic types of accelerators (including electrostatic accelerators, linacs, circular accelerators, storage rings & colliders).
- Physics of synchrotron radiation, wigglers and undulators (electrodynamics of moving point charges, properties of normal synchrotron radiation and undulator radiation)
- Beam optics and beam dynamics (e.g., magnetic lenses, beam properties, transverse & longitudinal oscillation and damping, many-particle systems)
- Magnetic technology for accelerators and synchrotron radiation sources
- Measurement and control of beam parameters
- Free-electron lasers
- Performance limits of accelerators (e.g., ultra-short electron pulses, high-intensity proton beams, beam-beam interactions in colliders)
- New technologies, current & future projects

**Workload**
180 hours consisting of attendance time (60 hours), preparation and wrap-up of the lecture and the integrated exercises (120 hours).
Literature

- E.J.N. Wilson: An Introduction to Particle Accelerators, Oxford University Press, 2001
- H. Wiedemann: Particle Acclerator Physics 1&2, Springer, 1993
4.5 Module: Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training [M-PHYS-106399]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Prof. Dr. Anke-Susanne Müller  
Dr. Anton Plech  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Optics and Photonics (Elective Optics and Photonics)  
Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Minor in Physics: Condensed Matter  
Minor in Physics: Optics and Photonics  
Minor in Physics: Experimental Particle Physics

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**Mandatory**

| T-PHYS–112943 | Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training | 4 CR | Baumbach, Müller, Plech, Stankov |

**Competence Certificate**

The regular attendance of the entire block course is required. The successful completion will be evaluated by a written final report on the basic principles and performance of a selected experiment. The results of the student group are to be presented in a final seminar with a communicated time interval (oral presentations or posters).

**Prerequisites**

none

**Competence Goal**

In the lectures, the basic accelerator types, their principles of operation and applications will be described. In particular, synchrotron radiation sources will be presented and in comparison to particle colliders for experimental high-energy particle physics will be discussed. The properties of the synchrotron radiation with the physical fundamentals, technical concepts of its generation and essential characteristics will be presented. Accelerator-relevant technologies and various methods for measuring and control of beam parameters will be discussed.

The basic concepts of synchrotron radiation and X-ray physics and their applications for the characterization of structure and dynamics of crystalline solids and nanostructures will be introduced. X-ray scattering/diffraction, -spectroscopy, and 2D and 3D X-ray imaging in real and reciprocal space, frequency and momentum spaces on laboratory sources and large-scale equipment will be presented.

Theoretical course content, tutorials and practical training are designed to enable students to understand high-tech accelerator instrumentation, to prepare and perform X-ray experiments on modern laboratory and large-scale equipment and apply the knowledge acquired in the lecture in a specific experiment.
Content
Introduction to accelerator physics with a focus on synchrotron radiation sources.

- Basic types of accelerators and their application
- Synchrotron radiation sources in comparison to colliders
- Physics of synchrotron radiation and its generation with wigglers and undulators
- Basics of beam optics and beam dynamics
- Measurement and control of beam parameters
- Free-electron lasers

Introduction to various application fields of the modern X-ray physics

- Theoretical and experimental fundamentals of X-ray physics, optics and analysis with emphasis on X-ray scattering, diffraction, spectroscopy, computed tomography, and X-ray microscopy
- Modern instrumentation in the X-ray laboratory and at large-scale facilities
- Examples of research from crystallography, nanoscience and life science on state-of-the-art X-ray equipment at the KIT Light Source.

Annotation
This module cannot be combined with an advanced seminar in the major in physics or second major in physics.

Workload
120 hours consisting of an attendance time (60 hours), a follow-up work (30 hours) and a preparation of seminar/poster incl. a rehearsal seminar (30 hours) during a two-weeks block course with lectures, tutorials and a practical training

Recommendation
Basics of classical electrodynamics, optics, quantum mechanics and basic knowledge of solid state physics.

Learning type
Two-weeks block course with lectures, tutorials and a practical training

Literature
- E. J. N. Wilson: An Introduction to Particle Accelerators, Oxford University Press, 2001
- H. Wiedemann: Particle Accelerator Physics 1&2, Springer, 1993
- K. Wille: Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen, Teubner Studienbücher
### 4.6 Module: Advanced Physics Laboratory Course [M-PHYS-101395]

<table>
<thead>
<tr>
<th>Responsible:</th>
<th>Dr. Gernot Guigas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PD Dr. Andreas Naber</td>
</tr>
<tr>
<td></td>
<td>Dr. Christoph Sürgers</td>
</tr>
<tr>
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<td>Dr. Joachim Wolf</td>
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<td>KIT Department of Physics</td>
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</table>

#### Mandatory

| T-PHYS-102479 | Advanced Physics Laboratory Course | 6 CR | Guigas, Naber, Sürgers, Wolf |

#### Competence Certificate

The proof of performance must be provided for each individual experiment. This includes preparation, execution, evaluation and preparation of a protocol. To pass the laboratory course, it is necessary that all experiments are performed and the protocols are approved by the respective supervisors. For details see [https://labs.physik.kit.edu/prakt-mod-fortg.php](https://labs.physik.kit.edu/prakt-mod-fortg.php).

#### Prerequisites

none

#### Competence Goal

Students learn modern experimental methods and advanced techniques in the experiments. In doing so, they deepen their understanding of physical concepts and increase their ability to contrast theory and experiment. They improve the safe operation of even complex measurement setups and gain advanced knowledge of measurement data acquisition and processing. They will also learn to ensure error-free operation of complex measurement processes. They will gain a routine handling of data analysis programs for the evaluation of experimental data. They will develop a critical approach to measurement results and thus improve their ability to assess their reliability. Through the careful elaboration of their own experimental results, they increase their writing competence and deepen the correct citation of external sources.

#### Content

Experiments from the fields of atomic physics, nuclear physics, solid state physics, biophysics, and modern optics/quantum optics. A list of the experiments can be found at [https://labs.physik.kit.edu/prakt-mod-fortg.php](https://labs.physik.kit.edu/prakt-mod-fortg.php).

#### Annotation

Mandatory participation in preliminary meeting with safety briefing and radiation protection instruction.

#### Workload

5 experiments, 180 hours consisting of attendance time (60 hours), preparation, evaluation of experiments and preparation of protocols (120 hours).

#### Literature

Textbooks of experimental physics. Special material for each individual experiment is provided.
4.7 Module: Advanced Seminar in the Area Condensed Matter [M-PHYS-102203]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Minor in Physics: Condensed Matter

**Credits**
4

**Grading scale**
Pass/fail

**Recurrence**
Each term

**Duration**
1 term

**Language**
German/English

**Level**
4

**Version**
3

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<td>T-PHYS-111451 Advanced Seminar: Units of Measurement and Metrology: No Guessing but Precise Measurement!</td>
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<td>T-PHYS-106129 Advanced Seminar: Modern Particle Accelerators and Research with Photons</td>
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<td>T-PHYS-106523 Advanced Seminar: Quantum Optics</td>
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<td>T-PHYS-111014 Advanced Seminar: Superconductivity - from Basics to Application</td>
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**Competence Certificate**
Study achievement. Own presentation as well as regular attendance.

**Prerequisites**
None

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
2. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
3. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
4. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
5. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

**Competence Goal**
Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**
Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**
120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)

**Literature**
Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
Module: Advanced Seminar in the Area Condensed Matter Theory [M-PHYS-102209]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
Second Major in Physics: Condensed Matter Theory
Minor in Physics: Condensed Matter Theory

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**Elective Adv. Sem. in Condensed Matter Theory (Elect: 4 credits)**

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<td>T-PHYS-104544</td>
<td>Advanced Seminar: Conformational Dynamics in Biomolecules</td>
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<td>Nienhaus, Wenzel</td>
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<td>T-PHYS-111323</td>
<td>Advanced Seminar: Hydrodynamics in Classical and Quantum Fluids</td>
<td>4 CR</td>
<td>Garst, Schmalian</td>
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<tr>
<td>T-PHYS-112802</td>
<td>Advanced Seminar: Phenomena of the Quantum World</td>
<td>4 CR</td>
<td>Garst, Schmalian, Shnirman</td>
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<td>T-PHYS-113133</td>
<td>Advanced Seminar: Quantum Mechanics: Selected Chapters</td>
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<td>T-PHYS-106523</td>
<td>Advanced Seminar: Quantum Optics</td>
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<td>Hunger, Naber, Rockstuhl, Wegener</td>
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<td>T-PHYS-111889</td>
<td>Advanced Seminar: Quantum Phase Transitions</td>
<td>4 CR</td>
<td>Garst</td>
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<tr>
<td>T-PHYS-110829</td>
<td>Advanced Seminar: Topology in Condensed Matter Systems</td>
<td>4 CR</td>
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<td>T-PHYS-111865</td>
<td>Advanced Seminar: Virtual Design of Materials</td>
<td>4 CR</td>
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**Competence Certificate**

Study achievement. Own presentation as well as regular attendance.

**Prerequisites**

None

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
3. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
4. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
5. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
6. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.

**Competence Goal**

Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**

Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**

120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)

**Literature**

Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
4.9 Module: Advanced Seminar in the Area Experimental Astroparticle Physics [M-PHYS-102207]

**Responsibility:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Minor in Physics: Experimental Astroparticle Physics

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**Elective Adv. Sem. in Exp. Astroparticle Physics (Elect: 4 credits)**

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<tr>
<td>T-PHYS-112801</td>
<td>Advanced Seminar: Accelerators and Detectors - Future Technologies for Research and Medicine</td>
<td>4 CR</td>
<td>Holzapfel, Husemann, Müller</td>
</tr>
<tr>
<td>T-PHYS-110293</td>
<td>Advanced Seminar: Astroparticle Physics</td>
<td>4 CR</td>
<td>Drexlin, Engel, Valerius</td>
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<tr>
<td>T-PHYS-112800</td>
<td>Advanced Seminar: Astroparticle Physics and Cosmology</td>
<td>4 CR</td>
<td>Drexlin, Engel, Valerius</td>
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<tr>
<td>T-PHYS-112236</td>
<td>Advanced Seminar: Unraveling the Puzzle of Dark Matter</td>
<td>4 CR</td>
<td>Mühleitner, Schwetz-Mangold</td>
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<tr>
<td>T-PHYS-106129</td>
<td>Advanced Seminar: Modern Particle Accelerators and Research with Photons</td>
<td>4 CR</td>
<td>Baumbach, Müller</td>
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</table>

**Competence Certificate**

Study achievement. Own presentation as well as regular attendance.

**Prerequisites**

None

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
3. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
4. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
5. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

**Competence Goal**

Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**

Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**

120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)

**Literature**

Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
Module: Advanced Seminar in the Area Experimental Particle Physics [M-PHYS-102206]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:**
1. Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
2. Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
3. Minor in Physics: Experimental Particle Physics

**Credits**
- **4**

**Grading scale**
- pass/fail

**Recurrence**
- Each term

**Duration**
- 1 term

**Language**
- German/English

**Level**
- 4

**Version**
- 3

**Elective Adv. Sem. in Exp. Particle Physics (Election: 4 credits)**

<table>
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<tr>
<td>T-PHYS-112801</td>
<td>Advanced Seminar: Accelerators and Detectors - Future Technologies for Research and Medicine</td>
<td>4 CR</td>
<td>Holzapfel, Husemann, Müller</td>
</tr>
<tr>
<td>T-PHYS-106525</td>
<td>Advanced Seminar: Experimental and Theoretical Methods in Particle Physics</td>
<td>4 CR</td>
<td>Gieseke, Heinrich, Quast, Zeppenfeld</td>
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<tr>
<td>T-PHYS-111864</td>
<td>Advanced Seminar: Low Energy Particle Physics (Belle II, LUXE)</td>
<td>4 CR</td>
<td>Ferber, Goldenzweig</td>
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<tr>
<td>T-PHYS-106129</td>
<td>Advanced Seminar: Modern Particle Accelerators and Research with Photons</td>
<td>4 CR</td>
<td>Baumbach, Müller</td>
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<tr>
<td>T-PHYS-112235</td>
<td>Advanced Seminar: Particle Physics</td>
<td>4 CR</td>
<td>Ferber, Husemann, Klute</td>
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<tr>
<td>T-PHYS-107566</td>
<td>Advanced Seminar: Particle Physics at the Highest Energy at the LHC</td>
<td>4 CR</td>
<td>Husemann, Klute, Müller, Wolf</td>
</tr>
<tr>
<td>T-PHYS-111863</td>
<td>Advanced Seminar: Particle Physics beyond the Standard Model</td>
<td>4 CR</td>
<td>Klute</td>
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<tr>
<td>T-PHYS-105791</td>
<td>Advanced Seminar: Particle Physics and Experimental Methods</td>
<td>4 CR</td>
<td>Goldenzweig, Husemann, Müller, Müller, Quast</td>
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**Competence Certificate**
Study achievement. Own presentation as well as regular attendance.

**Prerequisites**
None

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
3. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
4. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
5. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

**Competence Goal**
Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**
Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**
120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)
**Literature**
Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
Module: Advanced Seminar in the Area Nanophysics [M-PHYS-102204]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Minor in Physics: Nanophysics

**Credits** 4

**Grading scale** pass/fail

**Recurrence** Each term

**Duration** 1 term

**Language** German/English

**Level** 4

**Version** 3

### Elective Adv. Sem. in Nanophysics (Election: 4 credits)

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<td>T-PHYS-109971</td>
<td>Advanced Seminar: Recent Experiments in Quantum Physics</td>
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<tr>
<td>T-PHYS-104544</td>
<td>Advanced Seminar: Conformational Dynamics in Biomolecules</td>
<td>4 CR</td>
</tr>
<tr>
<td>T-PHYS-104560</td>
<td>Advanced Seminar: Light-optical Nanoscopy</td>
<td>4 CR</td>
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<tr>
<td>T-PHYS-111862</td>
<td>Advanced Seminar: Nano Optics</td>
<td>4 CR</td>
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<tr>
<td>T-PHYS-105789</td>
<td>Advanced Seminar: Optoelectronics - Fundamentals and Devices</td>
<td>4 CR</td>
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<td>T-PHYS-111014</td>
<td>Advanced Seminar: Superconductivity - from Basics to Application</td>
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<td>T-PHYS-111865</td>
<td>Advanced Seminar: Virtual Design of Materials</td>
<td>4 CR</td>
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**Competence Certificate**
Study achievement. Own presentation as well as regular attendance.

**Prerequisites**
None

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
3. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
4. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
5. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

**Competence Goal**
Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**
Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**
120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)

**Literature**
Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
4 MODULES

Module: Advanced Seminar in the Area Optics and Photonics [M-PHYS-102205]

4.12 Module: Advanced Seminar in the Area Optics and Photonics [M-PHYS-102205]

| Responsible: | Studiendekan Physik |
| Organisation: | KIT Department of Physics |
| Part of: | Major in Physics: Optics and Photonics (Elective Optics and Photonics) |
| Part of: | Second Major in Physics: Optics and Photonics |
| Part of: | Minor in Physics: Optics and Photonics |

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Elective Adv. Sem. in Optics and Photonics (Election: 4 credits)

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<td>T-PHYS-111451</td>
<td>Advanced Seminar: Units of Measurement and Metrology: No Guessing but Precise Measurement!</td>
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<td>Wulfhekel</td>
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<td>T-PHYS-104544</td>
<td>Advanced Seminar: Conformational Dynamics in Biomolecules</td>
<td>4 CR</td>
<td>Nienhaus, Wenzel</td>
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<tr>
<td>T-PHYS-104560</td>
<td>Advanced Seminar: Light-optical Nanoscopy</td>
<td>4 CR</td>
<td>Nienhaus</td>
</tr>
<tr>
<td>T-PHYS-111862</td>
<td>Advanced Seminar: Nano Optics</td>
<td>4 CR</td>
<td>Naber, Rockstuhl, Wegener</td>
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<tr>
<td>T-PHYS-105789</td>
<td>Advanced Seminar: Optoelectronics - Fundamentals and Devices</td>
<td>4 CR</td>
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<td>Advanced Seminar: Quantum Optics</td>
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<td>Hunger, Naber, Rockstuhl, Wegener</td>
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Competence Certificate
Study achievement. Own presentation as well as regular attendance.

Prerequisites
None

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
3. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
4. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
5. The module M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

Competence Goal
Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

Content
Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

Workload
120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)

Literature
Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
Module: Advanced Seminar in the Area Theoretical Particle Physics [M-PHYS-102208]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
- Second Major in Physics: Theoretical Particle Physics
- Minor in Physics: Theoretical Particle Physics

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**Elective Adv. Sem. in Theoretical Particle Physics (Elective: 4 credits)**

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<td>Advanced Seminar: Advanced Topics in Quantum Field Theory and Physics Beyond the Standard</td>
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<td>T-PHYS-106525</td>
<td>Advanced Seminar: Experimental and Theoretical Methods in Particle Physics</td>
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<td>T-PHYS-112804</td>
<td>Advanced Seminar: Flavor Physics</td>
<td>4 CR</td>
<td>Blanke, Kahlhöfer</td>
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<td>T-PHYS-106126</td>
<td>Advanced Seminar: General Relativity</td>
<td>4 CR</td>
<td>Klinkhamer</td>
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<td>T-PHYS-109974</td>
<td>Advanced Seminar: General Relativity II</td>
<td>4 CR</td>
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<td>T-PHYS-110830</td>
<td>Advanced Seminar: Higgs Meets Flavour</td>
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<td>T-PHYS-111452</td>
<td>Advanced Seminar: Physics Beyond the Standard Model</td>
<td>4 CR</td>
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<td>T-PHYS-113133</td>
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<td>T-PHYS-105793</td>
<td>Advanced Seminar: Special Relativity</td>
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<td>T-PHYS-112803</td>
<td>Advanced Seminar: The Matter Puzzle - Baryon Asymmetry, Dark Matter and Particle Physics</td>
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<td>T-PHYS-112236</td>
<td>Advanced Seminar: Unraveling the Puzzle of Dark Matter</td>
<td>4 CR</td>
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**Competence Certificate**

Study achievement. Own presentation as well as regular attendance.

**Prerequisites**

None

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter must not have been started.
2. The module M-PHYS-102204 - Advanced Seminar in the Area Nanophysics must not have been started.
3. The module M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics must not have been started.
4. The module M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics must not have been started.
5. The module M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics must not have been started.
6. The module M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory must not have been started.

**Competence Goal**

Students are able to present a specialized scientific topic. This includes collecting the scientific material, using a correct citation technique, considering didactic aspects, structuring the presentation, designing the slides, giving the actual presentation and answering questions from the audience.

**Content**

Together with the presentation techniques, depending on the choice of topic, special scientific subjects up to the current state of the art are communicated.

**Workload**

120 hours composed of attendance time (30 h), wrap-up of the seminar (30 h) and preparation of the own presentation incl. rehearsal presentation (60 h)
**Literature**
Will be communicated in the seminar, depending on the topic and specialization, textbooks and/or scientific articles are suitable.
Module: Array Techniques in Seismology (Graded) [M-PHYS-106196]

**Mandatory**

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<th>Credits</th>
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<th>Duration</th>
<th>Language</th>
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**Competence Certificate**

Grading is based on written reports on exercises. A detailed rating scheme is distributed during the first lecture together with information on the required length of the reports and rating criteria.

**Competence Goal**

The students understand basic principles of array techniques. This includes the increase in signal-to-noise ratio due to stacking or beamforming and the estimation of simple shear-wave velocity profiles. They know how to determine the slowness or ray parameter of an incoming wavefield as well as its backazimuth. These parameters are used to estimate the location of a seismic source. Furthermore, they know how to divide different phase arrivals using a vespagram or an f-k analysis.

The students are able to work self-organized on a specific issue of array seismology, e.g., the location of a nuclear test or the local shear-wave velocity structure underneath a local array. They are able to read and understand technical and scientific literature on array seismology. They can outline and analyze seismological cases in which array techniques can solve specific problems such as seismic phase identification or source location estimation.

**Content**

- Fundamentals of seismic waves
- Measurable parameters of seismic waves using arrays
- Determination of source locations
- Determination of underground properties
- Global seismic arrays and their role for monitoring nuclear tests and earthquakes
- Training on array software and application to seismological data sets

**Module grade calculation**

Reports on exercises need to be submitted which are individually graded. The final module grade is calculated as average of all individually graded reports. A detailed rating scheme is distributed during the first lecture.

**Workload**

Total workload: 120h which consist of 15h lecture at GPI, 15h reading of research papers and lecture material, 15h preparation and wrap-up of lecture, 15h guided exercise in the computing room at GPI to learn about array software (basic Linux and Python knowledge required), 30h self-organized training with array software and application to data sets, and 30h preparation of reports on exercises.

**Recommendation**

Participants need to know the basics of seismology.

**Literature**

Module: Astroparticle Physics I [M-PHYS-102075]

**Responsible:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Astroparticle Physics (Required Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Required Experimental Astroparticle Physics)

**Credits:** 8
**Grading scale:** Grade to a tenth
**Recurrence:** Each winter term
**Duration:** 1 term
**Language:** English
**Level:** 4
**Version:** 1

### Mandatory

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<td>8 CR</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102076 - Astroparticle Physics I (Minor)** must not have been started.

**Competence Goal**

Students will be introduced to the basic concepts of astroparticle physics. The lecture teaches both the theoretical concepts and the experimental methods of this new dynamic field of work at the interface of elementary particle physics, cosmology and astrophysics. Students will learn to understand the concepts through concrete case studies from current research and will be enabled to apply the learned methods independently.

**Methodological skills acquisition:**

- Understanding of the fundamentals of experimental astroparticle physics.
- Recognition of methodological cross-connections to elementary particle physics, astrophysics, and cosmology.
- Acquisition of the ability to present a current research topic independently as well as in a team setting
- Acquisition of the ability to implement the concepts and experimental methods in the master thesis

**Content**

The topics covered include a general introduction to the field with its fundamental issues, theoretical concepts and experimental methods. Corresponding to the very different energy scales (meV - 1020 eV) of astroparticle physics, the lecture is divided into a discussion of the processes in the thermal (low energies) and non-thermal (high energies) universe. A special focus of the lecture is a comprehensive presentation of modern experimental techniques, e.g. in the search for very rare processes. Based on this, in the second part of the lecture a comprehensive introduction to the "dark universe" and the search for dark matter is given.

The lecture is the basis of further lectures on this topic (Astroparticle Physics II).

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours)

**Recommendation**

Basic knowledge from the lecture "Nuclei and Particles".

**Literature**

- Donald Perkins, Particle Astrophysics (Oxford University Press, 2. Auflage, 2009)
- Claus Grupen, Astroparticle Physics (Springer, 2005)
4.16 Module: Astroparticle Physics I (Minor) [M-PHYS-102076]

**Responsible:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Astroparticle Physics

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**Mandatory**

| T-PHYS-104379 | Astroparticle Physics I (Minor) | 8 CR | Drexlin, Valerius |

**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102075 - Astroparticle Physics I must not have been started.

**Competence Goal**

Students will be introduced to the basic concepts of astroparticle physics. The lecture teaches both the theoretical concepts and the experimental methods of this new dynamic field of work at the interface of elementary particle physics, cosmology and astrophysics. Students will learn to understand the concepts through concrete case studies from current research and will be enabled to apply the learned methods independently.

**Methodological skills acquisition:**

- Understanding of the fundamentals of experimental astroparticle physics.
- Recognition of methodological cross-connections to elementary particle physics, astrophysics, and cosmology.
- Acquisition of the ability to present a current research topic independently as well as in a team setting
- Acquisition of the ability to implement the concepts and experimental methods in the master thesis

**Content**

The topics covered include a general introduction to the field with its fundamental issues, theoretical concepts and experimental methods. Corresponding to the very different energy scales (meV - 10^20 eV) of astroparticle physics, the lecture is divided into a discussion of the processes in the thermal (low energies) and non-thermal (high energies) universe. A special focus of the lecture is a comprehensive presentation of modern experimental techniques, e.g. in the search for very rare processes. Based on this, in the second part of the lecture a comprehensive introduction to the "dark universe" and the search for dark matter is given.

The lecture is the basis of further lectures on this topic (Astroparticle Physics II).

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**

Basic knowledge from the lecture "Nuclei and Particles".

**Literature**

- Donald Perkins, Particle Astrophysics (Oxford University Press, 2. Auflage, 2009)
- Claus Grupen, Astroparticle Physics (Springer, 2005)
Module: Astroparticle Physics II - Cosmic Rays, with ext. Exercises [M-PHYS-102525]

**Responsible:**  
Prof. Dr. Ralph Engel  
Dr. Markus Roth

**Organisation:**  
KIT Department of Physics

**Part of:**  
Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)  
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102082 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102078 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises must not have been started.
3. The module M-PHYS-103184 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students understand the basic terms and concepts of astrophysics of high-energy particles and apply them to the discussion of modern observational results. Typical approximations and considerations of astrophysics are comprehensible for the participants. In the extended exercises, students solve extensive problems in astroparticle physics and discuss them in the group.

**Content**

The lecture will be held as blackboard notes and with previously handed out visual material. Special emphasis will be placed on the explicit derivation of the essential relationships. Topics include astrophysical energy and size scales; cosmic ray properties; direct and indirect cosmic ray measurements; charged particle acceleration; galaxies and galactic magnetic fields; galactic and extra-galactic cosmic ray propagation; cosmic ray sources; particle physics and cosmic ray searches for exotic phenomena; high-energy neutrinos. Together with "Astroparticle Physics II: Gamma Radiation" the following semester, the two lectures provide a complete picture of high-energy particles with their underlying production and transport processes in the universe. The topic spectra of both lectures are designed in such a way that they can also be listened to individually.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours)

**Literature**

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (2nd Ed.)
- P. Schneider: Einführung in die Extragalaktische Astronomie und Kosmologie
- M. Longair: High Energy Astrophysics
- Thierry Courvoisier: High Energy Astrophysics
- Bradley W. Carroll and Dale Ostlie: An Introduction to Modern Astrophysics

Physics Master (Master of Science)  
Module Handbook as of 20/09/2023

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4.18 Module: Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) [M-PHYS-103184]

M

Responsible: Prof. Dr. Ralph Engel  
Dr. Markus Roth

Organisation: KIT Department of Physics  
Part of: Minor in Physics: Experimental Astroparticle Physics

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Mandatory

| T-PHYS-106317 | Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) | 8 CR | Engel, Roth |

Competence Certificate

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites

none

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-102082 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102078 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises must not have been started.
3. The module M-PHYS-102525 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises must not have been started.

Competence Goal

The students understand the basic terms and concepts of astrophysics of high-energy particles and apply them to the discussion of modern observational results. Typical approximations and considerations of astrophysics are comprehensible for the participants. In the extended exercises, students solve extensive problems in astroparticle physics and discuss them in the group.

Content

The lecture will be given as blackboard notes and with previously handed out visual material. Special emphasis will be placed on the explicit derivation of the essential relationships. Topics include astrophysical energy and size scales; cosmic ray properties; direct and indirect cosmic ray measurements; charged particle acceleration; galaxies and galactic magnetic fields; galactic and extra-galactic cosmic ray propagation; cosmic ray sources; particle physics and cosmic ray searches for exotic phenomena; high-energy neutrinos. Together with "Astroparticle Physics II: Gamma Radiation" the following semester, the two lectures provide a complete picture of high-energy particles with their underlying production and transport processes in the universe. The topic spectra of both lectures are designed in such a way that they can also be listened to individually.

Workload

240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

Literature

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (2nd Ed.)
- P. Schneider: Einführung in die Extragalaktische Astronomie und Kosmologie
- M. Longair: High Energy Astrophysic
- Thierry Courvoisier: High Energy Astrophysics
- Bradley W. Carroll and Dale Ostlie: An Introduction to Modern Astrophysics

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)  
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Mandatory**

| T-PHYS-102382 | Astroparticle Physics II - Cosmic Rays, without ext. Exercises | 6 CR | Engel, Roth |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102082 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102525 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises must not have been started.
3. The module M-PHYS-103184 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students understand the basic terms and concepts of astrophysics of high-energy particles and apply them to the discussion of modern observational results. Typical approximations and considerations of astrophysics are comprehensible for the participants. In the exercises, students solve selected problems in astroparticle physics and discuss them in the group.

**Content**

The lecture will be held as blackboard notes and with previously handed out visual material. Special emphasis will be placed on the explicit derivation of the essential relationships. Topics include astrophysical energy and size scales; cosmic ray properties; direct and indirect cosmic ray measurements; charged particle acceleration; galaxies and galactic magnetic fields; galactic and extra-galactic cosmic ray propagation; cosmic ray sources; particle physics and cosmic ray searches for exotic phenomena; high-energy neutrinos. Together with "Astroparticle Physics II: Gamma Radiation" the following semester, the two lectures provide a complete picture of high-energy particles with their underlying production and transport processes in the universe. The topic spectra of both lectures are designed in such a way that they can also be listened to individually.

**Workload**

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Literature**

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (2nd Ed.)
- P. Schneider: Einführung in die Extragalaktische Astronomie und Kosmologie
- M. Longair: High Energy Astrophysics
- Thierry Courvoisier: High Energy Astrophysics
- Bradley W. Carroll and Dale Ostlie: An Introduction to Modern Astrophysics
**M 4.20 Module: Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor) [M-PHYS-102082]**

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth

**Organisation:** KIT Department of Physics  
Part of: Minor in Physics: Experimental Astroparticle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102078 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises must not have been started.
2. The module M-PHYS-102525 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises must not have been started.
3. The module M-PHYS-103184 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) must not have been started.

**Competence Goal**
The students understand the basic terms and concepts of astrophysics of high-energy particles and apply them to the discussion of modern observational results. Typical approximations and considerations of astrophysics are comprehensible for the participants. In the exercises, students solve selected problems in astroparticle physics and discuss them in the group.

**Content**
The lecture will be held as blackboard notes and with previously handed out visual material. Special emphasis will be placed on the explicit derivation of the essential relationships. Topics include astrophysical energy and size scales; cosmic ray properties; direct and indirect cosmic ray measurements; charged particle acceleration; galaxies and galactic magnetic fields; galactic and extra-galactic cosmic ray propagation; cosmic ray sources; particle physics and cosmic ray searches for exotic phenomena; high-energy neutrinos. Together with "Astroparticle Physics II: Gamma Radiation" the following semester, the two lectures provide a complete picture of high-energy particles with their underlying production and transport processes in the universe. The topic spectra of both lectures are designed in such a way that they can also be listened to individually.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Literature**

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (2nd Ed.)
- P. Schneider: Einführung in die Extragalaktische Astronomie und Kosmologie
- M. Longair: High Energy Astrophysics
- Thierry Courvoisier: High Energy Astrophysics
- Bradley W. Carroll and Dale Ostlie: An Introduction to Modern Astrophysics
Module: Astroparticle Physics II - Gamma Rays and Neutrinos [M-PHYS-105683]

**Responsibility:** Prof. Dr. Guido Drexlin

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Mandatory**

| T-PHYS-111343 | Astroparticle Physics II - Gamma Rays and Neutrinos | 6 CR | Drexlin, Engel |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none, the lecture is designed complementary to the module Astroparticle Physics I and can be heard independently of it

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-105684 - Astroparticle Physics II - Gamma Rays and Neutrinos (Minor)** must not have been started.
2. The module **M-PHYS-105685 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor)** must not have been started.
3. The module **M-PHYS-105686 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises** must not have been started.

**Competence Goal**

After successful participation in this module, the student has an in-depth technical and survey knowledge in the field of high-energy astroparticle physics. He/she understands the most important formation processes of gamma rays and neutrinos, is able to interpret observed energy spectra of astrophysical objects and has basic knowledge of the astrophysics of galactic and extragalactic sources of high-energy particles.

**Content**

The fundamentals of astroparticle physics involving high-energy particles will be discussed, with emphasis on the application of gamma and neutrino astronomy to the study of astrophysical objects. Starting with the acceleration of charged particles, the first third of the lecture series introduces the main formation processes of gamma radiation, discusses the propagation of high-energy gamma radiation, and presents methods for detecting gamma radiation on Earth and in space. The second third of the lecture series discusses astrophysical objects and their image in gamma rays: supernova explosions and remnants, neutron stars and pulsars, black holes and Active Galactic Nuclei, and gamma-ray bursts. The course is rounded out by an introduction to the fundamentals and current issues in astronomy involving high-energy neutrinos. Together with the course "Astroparticle Physics II: Cosmic Rays", which is offered in the WS, a complete picture of high-energy particles with their underlying production and transport processes in our universe is obtained. The subject spectra of both lectures are complementary in nature and can be heard independently, but complement each other appropriately. The lecture ATP II "Gamma Rays and Neutrinos" is complementary to further in-depth lectures (Astroparticle Physics II "Cosmic Rays" or "Particles and Stars").

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Basic knowledge of the physics of particles and nuclei and of experimental methods in this area is assumed.
Literature

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (Cambridge)
- M.S. Longair: High Energy Astrophysics (Cambridge)
- H. Bradt: Astrophysics Processes (Cambridge)

Further literature will be given in the lecture.
4.22 Module: Astroparticle Physics II - Gamma Rays and Neutrinos (Minor) [M-PHYS-105684]

**Responsibility:** Prof. Dr. Guido Drexlin

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Astroparticle Physics

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**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none, the lecture is designed complementary to the module Astroparticle Physics I and can be heard independently of it.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105683 - Astroparticle Physics II - Gamma Rays and Neutrinos must not have been started.
2. The module M-PHYS-105685 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-105686 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises must not have been started.

**Competence Goal**

After successful participation in this module, the student has an in-depth technical and survey knowledge in the field of high-energy astroparticle physics. He/she understands the most important formation processes of gamma rays and neutrinos, is able to interpret observed energy spectra of astrophysical objects and has basic knowledge of the astrophysics of galactic and extragalactic sources of high-energy particles.

**Content**

The fundamentals of astroparticle physics involving high-energy particles will be discussed, with emphasis on the application of gamma and neutrino astronomy to the study of astrophysical objects. Starting with the acceleration of charged particles, the first third of the lecture series introduces the main formation processes of gamma radiation, discusses the propagation of high-energy gamma radiation, and presents methods for detecting gamma radiation on Earth and in space. The second third of the lecture series discusses astrophysical objects and their image in gamma rays: supernova explosions and remnants, neutron stars and pulsars, black holes and active galactic nuclei, and gamma-ray bursts. The course is rounded out by an introduction to the fundamentals and current issues in astronomy involving high-energy neutrinos.

Together with the course "Astroparticle Physics II: Cosmic Rays", which is offered in the WS, a complete picture of high-energy particles with their underlying production and transport processes in our universe is obtained. The subject spectra of both lectures are complementary in nature and can be heard independently, but complement each other appropriately. The lecture ATP II " Gamma Rays and Neutrinos" is complementary to further in-depth lectures (Astroparticle Physics II "Cosmic Rays" or "Particles and Stars").

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**

Basic knowledge of the physics of particles and nuclei and of experimental methods in this area is assumed.
**Literature**

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (Cambridge)
- M.S. Longair: High Energy Astrophysics (Cambridge)
- H. Bradt: Astrophysics Processes (Cambridge)

Further literature will be given in the lecture.
4.23 Module: Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises [M-PHYS-105686]

Responsibility: Prof. Dr. Guido Drexlin

Organisation: KIT Department of Physics

Part of: Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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Mandatory

T-PHYS-111346 Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises 8 CR Drexlin, Engel

Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites

none, the lecture is designed complementary to the module Astroparticle Physics I and can be heard independently of it

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-105683 - Astroparticle Physics II - Gamma Rays and Neutrinos must not have been started.
2. The module M-PHYS-105684 - Astroparticle Physics II - Gamma Rays and Neutrinos (Minor) must not have been started.
3. The module M-PHYS-105685 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor) must not have been started.

Competence Goal

After successful participation in this module, the student has an in-depth technical and survey knowledge in the field of high-energy astroparticle physics. He/she understands the most important formation processes of gamma rays and neutrinos, is able to interpret observed energy spectra of astrophysical objects and has basic knowledge of the astrophysics of galactic and extragalactic sources of high-energy particles.

Content

The fundamentals of astroparticle physics involving high-energy particles will be discussed, with emphasis on the application of gamma and neutrino astronomy to the study of astrophysical objects. Starting with the acceleration of charged particles, the first third of the lecture series introduces the main formation processes of gamma radiation, discusses the propagation of high-energy gamma radiation, and presents methods for detecting gamma radiation on Earth and in space. The second third of the lecture series discusses astrophysical objects and their image in gamma rays: supernova explosions and remnants, neutron stars and pulsars, black holes and Active Galactic Nuclei, and gamma-ray bursts. The course is rounded out with an introduction to the fundamentals and current issues in astronomy involving high-energy neutrinos.

Together with the course "Astroparticle Physics II: Cosmic Rays", which is offered in the WS, a complete picture of high-energy particles with their underlying production and transport processes in our universe is obtained. The subject spectra of both lectures are complementary in nature and can be heard independently, but complement each other appropriately. The lecture ATP II " Gamma Rays and Neutrinos" is complementary to further in-depth lectures (Astroparticle Physics II " Cosmic Rays" or "Particles and Stars").

Workload

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

Recommendation

Basic knowledge of the physics of particles and nuclei and of experimental methods in this area is assumed.
Literature

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (Cambridge)
- M.S. Longair: High Energy Astrophysics (Cambridge)
- H. Bradt: Astrophysics Processes (Cambridge)

Further literature will be given in the lecture.
### 4.24 Module: Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor) [M-PHYS-105685]

| Responsible: | Prof. Dr. Guido Drexlin |
| Organisation: | KIT Department of Physics |
| Part of: | Minor in Physics: Experimental Astroparticle Physics |

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none, the lecture is designed complementary to the module Astroparticle Physics I and can be heard independently of it

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module **M-PHYS-105683 - Astroparticle Physics II - Gamma Rays and Neutrinos** must not have been started.
2. The module **M-PHYS-105684 - Astroparticle Physics II - Gamma Rays and Neutrinos (Minor)** must not have been started.
3. The module **M-PHYS-105686 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises** must not have been started.

**Competence Goal**
After successful participation in this module, the student has an in-depth technical and survey knowledge in the field of high-energy astroparticle physics. He/she understands the most important formation processes of gamma rays and neutrinos, is able to interpret observed energy spectra of astrophysical objects and has basic knowledge of the astrophysics of galactic and extragalactic sources of high-energy particles.

**Content**
The fundamentals of astroparticle physics involving high-energy particles will be discussed, with emphasis on the application of gamma and neutrino astronomy to the study of astrophysical objects. Starting with the acceleration of charged particles, the first third of the lecture series introduces the main formation processes of gamma radiation, discusses the propagation of high-energy gamma radiation, and presents methods for detecting gamma radiation on Earth and in space. The second third of the lecture series discusses astrophysical objects and their image in gamma rays: supernova explosions and remnants, neutron stars and pulsars, black holes and Active Galactic Nuclei, and gamma-ray bursts. The course is rounded out by an introduction to the fundamentals and current issues in astronomy involving high-energy neutrinos.

Together with the course "Astroparticle Physics II: Cosmic Rays", which is offered in the WS, a complete picture of high-energy particles with their underlying production and transport processes in our universe is obtained. The subject spectra of both lectures are complementary in nature and can be heard independently, but complement each other appropriately. The lecture ATP II "Gamma Rays and Neutrinos" is complementary to further in-depth lectures (Astroparticle Physics II "Cosmic Rays" or "Particles and Stars").

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**
Basic knowledge of the physics of particles and nuclei and of experimental methods in this area is assumed.
Literature

- T.K. Gaisser, R. Engel, E. Resconi: Cosmic Rays and Particle Physics (Cambridge)
- M.S. Longair: High Energy Astrophysics (Cambridge)
- H. Bradt: Astrophysics Processes (Cambridge)

Further literature will be given in the lecture.
**Module: Astroparticle Physics II - Particles and Stars, with ext. Exercises [M-PHYS-102527]**

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)  
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Mandatory**

| T-PHYS-105110 | Astroparticle Physics II - Particles and Stars, with ext. Exercises | 8 CR | Drexlin, Valerius |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

If Experimental Astroparticle Physics is chosen as the main subject, the lecture Astroparticle Physics I or Cosmology must also be taken. The lecture ATP II - Particles and Stars is complementary to other in-depth lectures (Astroparticle Physics II - Cosmic Rays, Gamma Rays).

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102086 - Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor)** must not have been started.
2. The module **M-PHYS-102081 - Astroparticle Physics II - Particles and Stars, without ext. Exercises** must not have been started.
3. The module **M-PHYS-103186 - Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor)** must not have been started.

**Competence Goal**

Students expand their knowledge of astroparticle physics to include the areas of stellar astrophysics, neutrino physics, and multimessenger astronomy. They are able to name current and past problems and understand approaches to solving them, and are familiar with current methods and technologies in research. Cross connections to other areas of physics, especially elementary particle physics are recognized.

Students are able to understand and construct simple models to analyze problems and concepts quantitatively. They are also able to independently familiarize themselves with current research results and to present and discuss their findings and calculations.

Furthermore, the students deepen their knowledge of an experiment in astroparticle physics through a practical exercise and are able to evaluate and interpret measurement data.

**Content**

Building on the introductory lectures Astroparticle Physics I and Cosmology, the lecture gives an in-depth insight into two key areas of modern experimental astroparticle physics.

In the first area, a comprehensive look at the fundamentals of experimental neutrino physics is provided. The focus is on the field of neutrino properties. Topics covered include an introduction to the phenomenon of neutrino oscillations including recent results on solar & atmospheric neutrinos, as well as reactor and accelerator neutrino experiments. In addition, emphasis will be placed on experiments for direct neutrino mass determination and the search for neutrinoless double beta decay.

In the second part of the lecture, an introduction is given to the field of stellar astrophysics with a special emphasis on late stellar phases. These are characterized by degenerate matter (white dwarfs and neutron stars) and form the precursors of supernova explosions (thermonuclear and core collapse SNe). Finally, methods of ATP to detect these processes with neutrino detectors and gravitational wave observatories will be discussed.

The lecture emphasizes an in-depth presentation of fundamental physical processes and experimental methods in astroparticle physics.
Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

Recommendation
Basic knowledge of the physics of particles and nuclei and of fundamental experimental methods in this area is assumed.

Literature
- Donald Perkins, Particle Astrophysics (Oxford University Press)
- Kai Zuber, Neutrino physics (Routledge Chapman & Hall), 2nd Edition
- H.V. Klapdor-Kleingrothaus & Kai Zuber, Teilchenastrophysik (Teubner)

Further literature will be announced in the lecture.
4.26 Module: Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor)  
[M-PHYS-103186]

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Astroparticle Physics

**Credits:** 8  
**Grading scale:** pass/fail  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** German  
**Level:** 4  
**Version:** 1

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**Competence Certificate**  
Die Studienleistung wird durch erfolgreiche Teilnahme am Übungsbetrieb erbracht. Die Details werden in der ersten Vorlesung oder beim ersten Übungstermin bekannt gegeben.

**Prerequisites**  
If Experimental Astroparticle Physics is chosen as the main subject, the lecture Astroparticle Physics I or Cosmology must also be taken. The lecture ATP II - Particles and Stars is complementary to other in-depth lectures (Astroparticle Physics II - Cosmic Rays, Gamma Rays).

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102086 - Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102081 - Astroparticle Physics II - Particles and Stars, without ext. Exercises must not have been started.
3. The module M-PHYS-102527 - Astroparticle Physics II - Particles and Stars, with ext. Exercises must not have been started.

**Competence Goal**  
Students expand their knowledge of astroparticle physics to include the areas of stellar astrophysics, neutrino physics, and multimessenger astronomy. They are able to name current and past problems and understand approaches to solving them, and are familiar with current methods and technologies in research. Cross connections to other areas of physics, especially elementary particle physics are recognized.

Students are able to understand and construct simple models to analyze problems and concepts quantitatively. They are also able to independently familiarize themselves with current research results and to present and discuss their findings and calculations.

Furthermore, the students deepen their knowledge of an experiment in astroparticle physics through a practical exercise and are able to evaluate and interpret measurement data.

**Content**  
Building on the introductory lectures Astroparticle Physics I and Cosmology, the lecture gives an in-depth insight into two key areas of modern experimental astroparticle physics.

In the first area, a comprehensive look at the fundamentals of experimental neutrino physics is provided. The focus is on the field of neutrino properties. Topics covered include an introduction to the phenomenon of neutrino oscillations including recent results on solar & atmospheric neutrinos, as well as reactor and accelerator neutrino experiments. In addition, emphasis will be placed on experiments for direct neutrino mass determination and the search for neutrinoless double beta decay.

In the second part of the lecture, an introduction is given to the field of stellar astrophysics with a special emphasis on late stellar phases. These are characterized by degenerate matter (white dwarfs and neutron stars) and form the precursors of supernova explosions (thermonuclear and core collapse SNe). Finally, methods of ATP to detect these processes with neutrino detectors and gravitational wave observatories will be discussed.

The lecture emphasizes an in-depth presentation of fundamental physical processes and experimental methods in astroparticle physics.

**Workload**  
240 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (195 hours).
**Recommendation**
Basic knowledge of the physics of particles and nuclei and of fundamental experimental methods in this area is assumed.

**Literature**
- Donald Perkins, *Particle Astrophysics* (Oxford University Press)
- H.V. Klager-Kleingrothaus & Kai Zuber, *Teilchenastrophysik* (Teubner)

Further literature will be announced in the lecture.
Module: Astroparticle Physics II - Particles and Stars, without ext. Exercises [M-PHYS-102081]

**Responsibility:** Prof. Dr. Guido Drexlin

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Astroparticle Physics (Further Required Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

If Experimental Astroparticle Physics is chosen as the main subject, the lecture Astroparticle Physics I or Cosmology must also be taken. The lecture ATP II - Particles and Stars is complementary to other in-depth lectures (Astroparticle Physics II - Cosmic Rays, Gamma Rays).

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102086 - Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102527 - Astroparticle Physics II - Particles and Stars, with ext. Exercises must not have been started.
3. The module M-PHYS-103186 - Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Students expand their knowledge of astroparticle physics to include the areas of stellar astrophysics, neutrino physics, and multimessenger astronomy. They are able to name current and past problems and understand approaches to solving them, and are familiar with current methods and technologies in research. Cross connections to other areas of physics, especially elementary particle physics, are recognized.

Students are able to understand and construct simple models to analyze problems and concepts quantitatively. In addition, they are able to independently familiarize themselves with current research results and to present and discuss their findings and calculations.

**Content**

Building on the introductory lectures Astroparticle Physics I and Cosmology, the lecture gives an in-depth insight into two key areas of modern experimental astroparticle physics.

In the first area, a comprehensive look at the fundamentals of experimental neutrino physics is provided. The focus is on the field of neutrino properties. Topics covered include an introduction to the phenomenon of neutrino oscillations including recent results on solar & atmospheric neutrinos, as well as reactor and accelerator neutrino experiments. In addition, emphasis will be placed on experiments for direct neutrino mass determination and the search for neutrinoless double beta decay.

In the second part of the lecture, an introduction is given to the field of stellar astrophysics with a special emphasis on late stellar phases. These are characterized by degenerate matter (white dwarfs and neutron stars) and form the precursors of supernova explosions (thermonuclear and core collapse SNe). Finally, methods of ATP to detect these processes with neutrino detectors and gravitational wave observatories will be discussed.

The lecture emphasizes an in-depth presentation of fundamental physical processes and experimental methods in astroparticle physics.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).
**Recommendation**
Basic knowledge of the physics of particles and nuclei and of fundamental experimental methods in this area is assumed.

**Literature**

- Donald Perkins, *Particle Astrophysics* (Oxford University Press)
- H.V. Klapdor-Kleingrothaus & Kai Zuber, *Teilchenastrophysik* (Teubner)

Further literature will be announced in the lecture.
4.28 Module: Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor) [M-PHYS-102086]

**Responsible:** Prof. Dr. Guido Drexlin  
**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Astroparticle Physics

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**Drexlin, Valerius**

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
If Experimental Astroparticle Physics is chosen as the main subject, the lecture Astroparticle Physics I or Cosmology must also be taken. The lecture ATP II - Particles and Stars is complementary to other in-depth lectures (Astroparticle Physics II - Cosmic Rays, Gamma Rays).

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module **M-PHYS-102081 - Astroparticle Physics II - Particles and Stars, without ext. Exercises** must not have been started.
2. The module **M-PHYS-102527 - Astroparticle Physics II - Particles and Stars, with ext. Exercises** must not have been started.
3. The module **M-PHYS-103186 - Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor)** must not have been started.

**Competence Goal**
Students expand their knowledge of astroparticle physics to include the areas of stellar astrophysics, neutrino physics, and multimessenger astronomy. They are able to name current and past problems and understand approaches to solving them, and are familiar with current methods and technologies in research. Cross connections to other areas of physics, especially elementary particle physics are recognized.

Students are able to understand and construct simple models to analyze problems and concepts quantitatively. In addition, they are able to independently familiarize themselves with current research results and to present and discuss their findings and calculations.

**Content**
Building on the introductory lectures Astroparticle Physics I and Cosmology, the lecture gives an in-depth insight into two key areas of modern experimental astroparticle physics.

In the first area, a comprehensive look at the fundamentals of experimental neutrino physics is provided. The focus is on the field of neutrino properties. Topics covered include an introduction to the phenomenon of neutrino oscillations including recent results on solar & atmospheric neutrinos, as well as reactor and accelerator neutrino experiments. In addition, emphasis will be placed on experiments for direct neutrino mass determination and the search for neutrinoless double beta decay.

In the second part of the lecture, an introduction is given to the field of stellar astrophysics with a special emphasis on late stellar phases. These are characterized by degenerate matter (white dwarfs and neutron stars) and form the precursors of supernova explosions (thermonuclear and core collapse SNe). Finally, methods of ATP to detect these processes with neutrino detectors and gravitational wave observatories will be discussed.

The lecture emphasizes an in-depth presentation of fundamental physical processes and experimental methods in astroparticle physics.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**
Basic knowledge of the physics of particles and nuclei and of fundamental experimental methods in this area is assumed.
Literature

- Donald Perkins, Particle Astrophysics (Oxford University Press)
- Kai Zuber, Neutrino physics (Routledge Chapman & Hall), 2nd Edition
- H.V. Klapdor-Kleingrothaus & Kai Zuber, Teilchenastrophysik (Teubner)

Further literature will be announced in the lecture.
Module: Basics of Nanotechnology I [M-PHYS-102097]

Responsible: apl. Prof. Dr. Gernot Goll
Organisation: KIT Department of Physics
Part of: Major in Physics: Nanophysics (mandatory)
Second Major in Physics: Nanophysics (mandatory)

Credits 4
Grading scale Grade to a tenth
Recurrence Each winter term
Duration 1 term
Language English
Level 4
Version 1

Mandatory
T-PHYS-102529 Basics of Nanotechnology I 4 CR Goll

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102096 - Basics of Nanotechnology I (Minor) must not have been started.

Competence Goal
Students deepen their knowledge in one area of nano-physics, master the relevant theoretical concepts and are familiar with basic techniques and measurement methods of nano-analytics and lithography.

Content
Introduction to central areas of nanotechnology;
Teaching of the conceptual, theoretical and, in particular, methodological fundamentals:

- Methods of imaging and characterization (nanoanalytics)
  Basic concepts of electron microscopy and associated analytical capabilities are covered in an introductory manner. Scanning probe techniques such as tunneling and force microscopy for the investigation and imaging of conductive and insulating sample surfaces, respectively, are discussed. Complementary spectroscopic capabilities of the scanning probe techniques will be explained.
- Methods of nanostructure fabrication (lithography and self-assembly)
  Along the individual process steps from coating and exposure to structure transfer by etching and vapor deposition, the methods used will be explained, their application limits discussed and current developments highlighted.

The lecture "Nanotechnology II" covers application areas and current research topics in the summer semester.

Workload
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation. (90 hours)

Recommendation
Basic knowledge of solid state physics and quantum mechanics is expected.

Literature
For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.
Module: Basics of Nanotechnology I (Minor) [M-PHYS-102096]

**Responsibility:** apl. Prof. Dr. Gernot Goll

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Nanophysics

### Credits
- 4

### Grading scale
- pass/fail

### Recurrence
- Each winter term

### Duration
- 1 term

### Language
- English

### Level
- 4

### Version
- 1

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#### Competence Certificate
The course credit is achieved through participation in the lecture and an oral review of success, e.g. in terms of a colloquium or a short presentation covering the topics of the lecture. Details will be announced in the first lecture.

#### Prerequisites
none

#### Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102097 - Basics of Nanotechnology I must not have been started.

#### Competence Goal
Students deepen their knowledge in one area of nano-physics, master the relevant theoretical concepts and are familiar with basic techniques and measurement methods of nano-analytics and lithography.

#### Content
Introduction to central areas of nanotechnology;
Teaching of the conceptual, theoretical and, in particular, methodological fundamentals:

- Methods of imaging and characterization (nanoanalytics)
  Basic concepts of electron microscopy and associated analytical capabilities are covered in an introductory manner. Scanning probe techniques such as tunneling and force microscopy for the investigation and imaging of conductive and insulating sample surfaces, respectively, are discussed. Complementary spectroscopic capabilities of the scanning probe techniques will be explained.
- Methods of nanostructure fabrication (lithography and self-assembly)
  Along the individual process steps from coating and exposure to structure transfer by etching and vapor deposition, the methods used will be explained, their application limits discussed and current developments highlighted.

The lecture "Nanotechnology II" covers application areas and current research topics in the summer semester.

#### Workload
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours)

#### Recommendation
Basic knowledge of solid state physics and quantum mechanics is expected.

#### Literature
For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.
4.31 Module: Basics of Nanotechnology II [M-PHYS-102100]

**Responsible:** apl. Prof. Dr. Gernot Goll

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Nanophysics (mandatory)
Second Major in Physics: Nanophysics (mandatory)

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**Mandatory**

| T-PHYS-102531 | Basics of Nanotechnology II | 4 CR | Goll |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102099 - Basics of Nanotechnology II (Minor) must not have been started.

**Competence Goal**

The student deepens his knowledge in the field of nanophysics, masters the relevant theoretical concepts and is familiar with the basic application areas of nanophysics. The student is able to interpret current data and figures from the scientific literature and to present the current state of research as well as important "open questions".

**Content**

Introduction to central areas of nanotechnology

Teaching of the conceptual, theoretical and especially methodological basics;

Applications and current developments in the fields of nanoelectronics, nano-optics, nanomechanics, nanotribology, biological nanostructures, self-organized nanostructures, among others.

In addition, the lecture "Fundamentals of Nanotechnology I" in the winter semester deals with methods of imaging, characterization and fabrication of nanostructures.

**Workload**

120 hours consisting of attendance time (30 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (90 hours)

**Recommendation**

Basic knowledge of solid state physics and quantum mechanics is expected.

**Literature**

For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.
4.32 Module: Basics of Nanotechnology II (Minor) [M-PHYS-102099]

Responsible: apl. Prof. Dr. Gernot Goll
Organisation: KIT Department of Physics
Part of: Minor in Physics: Nanophysics

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Mandatory

| T-PHYS-102530 | Basics of Nanotechnology II (Minor) | 4 CR | Goll |

Competence Certificate
The course credit is achieved through participation in the lecture and an oral review of success, e.g. in terms of a colloquium or a short presentation covering the topics of the lecture. Details will be announced in the first lecture.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102100 - Basics of Nanotechnology II must not have been started.

Competence Goal
The student deepens his knowledge in the field of nanophysics, masters the relevant theoretical concepts and is familiar with the basic application areas of nanophysics. The student is able to interpret current data and figures from the scientific literature and to present the current state of research as well as important "open questions".

Content
Introduction to central areas of nanotechnology
Teaching of the conceptual, theoretical and especially methodological basics;
Applications and current developments in the fields of nanoelectronics, nano-optics, nanomechanics, nanotribology, biological nanostructures, self-organized nanostructures, among others.
In addition, the lecture "Fundamentals of Nanotechnology I" in the winter semester deals with methods of imaging, characterization and fabrication of nanostructures.

Workload
120 hours consisting of attendance time (30 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (90 hours)

Recommendation
Basic knowledge of solid state physics and quantum mechanics is expected.

Literature
For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.
4.33 Module: Block Practical Course: ETP Data Science [M-PHYS-106530]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. rer. nat. Jan Kieseler  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Minor in Physics: Experimental Particle Physics  
- Minor in Physics: Experimental Astroparticle Physics

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<td>2 CR</td>
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**Competence Certificate**  
The regular attendance of the entire block course is required. The successful completion will be evaluated by a short oral test on the preparatory work and a final presentation in the week after the course.

**Prerequisites**  
None (preparatory material and exercises will be sent around in advance of the course)

**Competence Goal**  
The students are familiar with the basic concepts of calorimetry, the simulation of particle showers, and the use of machine learning for the determination of the incident particle energy. This includes the interaction of high energetic particles with matter, the evolution of electromagnetic and hadronic showers through the material, and the detection of signals for determining the original particle energy. The students know different neural network architectures in addition to classical methods for energy reconstruction based on these signals.

The theoretical course content, tutorials and practical training are combined and designed to enable students to develop an intuitive understanding of the advantages and disadvantages of different calorimeter types for high energy physics experiments. Furthermore, they can simulate the response of those calorimeters with state-of-the-art simulation software, explore different geometries, and are able to understand, choose, and train suitable neural network architectures for energy reconstruction hands-on.

**Content**  
- Introduction to high-energy physics calorimetry  
- Hands-on simulation of calorimeter designs with the Geant4 simulation software  
- Hands-on implementation of neural network building blocks  
- Application of advanced neural networks to particle energy reconstruction in calorimeters

**Annotation**  
This module cannot be combined with an advanced seminar or any other non-graded module in the major in physics or second major in physics.

**Workload**  
60 hours consisting of preparatory work (15 hours) in advance to the course start, an attendance time (30 hours) during the one-week block course with lectures, tutorials and a practical training, and a preparation of a final presentation (15 hours) after the block course.

**Recommendation**  
Basic knowledge of python and neural networks is helpful

**Learning type**  
One-week block course with lectures, tutorials and a practical training
**Literature**
A list will be sent around in advance of the course.
Module: Classical Theory of Gauge Fields [M-PHYS-105934]

**Responsible:** Prof. Dr. Ulrich Nierste  
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-111943 | Classical Theory of Gauge Fields | 4 CR | Nierste, Ziegler |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

The participants have a deeper understanding of field theoretical concepts such as gauge invariance, Noether theorem, Goldstone theorem, Higgs mechanism and topological solitons. Students are familiar with the representation theory of non-abelian Lie groups and the construction of gauge invariant Lagrangians.

**Content**

This module teaches the classical aspects of gauge field theories as an introduction or complement to quantum field theory. As an introduction and motivation, the gauge principle in electrodynamics is treated before the foundations of classical field theory are discussed. After an introduction to the representation theory of Lie groups, non-Abelian gauge field theories are discussed, in particular the construction of gauge-invariant Lagrangian densities. Furthermore, spontaneous breaking of global and gauge symmetries in the context of the Higgs mechanism is considered. Finally, non-linear aspects of the field equations are discussed using topological solitons and monopoles as examples, and the underlying elements of homotopy theory are presented.

**Workload**

120 hours consisting of attendance time (30 hours), wrap-up of the lecture and preparation of the exam (90 hours).

**Literature**

Will be stated on the lecture website and in the lecture itself.
Module: Computational Condensed Matter Physics [M-PHYS-104862]

Responsible:  Prof. Dr. Wolfgang Wenzel
Organisation: KIT Department of Physics
Part of:  
  Major in Physics: Nanophysics (Elective Nanophysics)
  Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
  Second Major in Physics: Nanophysics (Elective Nanophysics)
  Second Major in Physics: Condensed Matter Theory

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Mandatory

T-PHYS-109895  Computational Condensed Matter Physics  12 CR  Wenzel

Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites

none

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-104863 - Computational Condensed Matter Physics (Minor) must not have been started.

Competence Goal

In recent decades, simulation has established itself as a third pillar of research alongside analytical theory and experiment. It often bridges the gap from principled insights to applications to specific systems. Students develop and gain knowledge of materials-specific simulation for condensed matter systems, from ordered solids to soft matter. Students become familiar with available simulation techniques and apply them to specific problems in condensed matter. They acquire key skills in the use of open-source software to solve simulation problems in condensed matter, in autonomy, in synthesizing the results of different methods for a holistic description in the simulation of material properties.

Content

- Quantum mechanics of many-particle systems
- Methods of quantum chemistry (LCAO, Hartree Fock, density functional theory, electron correlations)
- Applications to molecules and solids
- Simulation methods for classical many-particle systems (Monte Carlo, molecular dynamics)
- Applications to structure formation in polymers, glasses, and solids.
- Introduction to multiscale simulations (QM/MM, multilevel methods) and artificial intelligence techniques.
- Modeling of electronic transport

Workload

360 hours consisting of attendance time (60 hours lecture, 30 hours exercises), follow-up of the lecture incl. exam preparation and working on the exercises (270 hours)

Literature

- Mark Newman: Computational Physics
- Szabo: Modern Quantum Chemistry
- Kurt Binder: Monte Carlo Simulation in Statistical Physics
- Leach: Molecular Modeling
### 4.36 Module: Computational Condensed Matter Physics (Minor) [M-PHYS-104863]

**Responsible:** Prof. Dr. Wolfgang Wenzel  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Minor in Physics: Nanophysics  
- Minor in Physics: Condensed Matter Theory

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**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104862 - Computational Condensed Matter Physics must not have been started.

**Competence Goal**

In recent decades, simulation has established itself as a third pillar of research alongside analytical theory and experiment. It often bridges the gap from principled insights to applications to specific systems. Students develop and gain knowledge of materials-specific simulation for condensed matter systems, from ordered solids to soft matter. Students become familiar with available simulation techniques and apply them to specific problems in condensed matter. They acquire key skills in the use of open-source software to solve simulation problems in condensed matter, in autonomy, in synthesizing the results of different methods for a holistic description in the simulation of material properties.

**Content**

- Quantum mechanics of many-particle systems  
- Methods of quantum chemistry (LCAO, Hartree Fock, density functional theory, electron correlations)  
- Applications to molecules and solids  
- Simulation methods for classical many-particle systems (Monte Carlo, molecular dynamics)  
- Applications to structure formation in polymers, glasses, and solids.  
- Introduction to multiscale simulations (QM/MM, multilevel methods) and artificial intelligence techniques.  
- Modeling of electronic transport

**Workload**

360 hours consisting of attendance time (60 hours lecture, 30 hours exercises), wrap-up of the lecture and work on the exercises (270 hours)

**Recommendation**

Knowledge of quantum mechanics and solid state theory.

**Literature**

- Mark Newman: Computational Physics  
- Szabo: Modern Quantum Chemistry  
- Kurt Binder: Monte Carlo Simulation in Statistical Physics  
- Leach: Molecular Modeling
**Module: Computational Methods for Particle Physics and Cosmology [M-PHYS-106117]**

**Responsible:** TT-Prof. Dr. Felix Kahlhöfer  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-112378 | Computational Methods for Particle Physics and Cosmology | 6 CR | Kahlhöfer |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

Students know how to confront theoretical models with experimental data in order to identify preferred models and promising measurements. Students can use tools like FeynRules and MadGraph to calculate cross sections and generate events for processes beyond the Standard Model of particle physics. Students know how to infer model parameters from data using Markov chain Monte Carlos and perform a Bayesian model comparison. Students have some experience with machine learning and understand the range of possible applications of deep neural networks in particle physics and cosmology.

**Content**

The aim of this module is to explore modern methods for connecting theoretical models in particle physics and cosmology with data from experiments and observations. After a general introduction into the fundamental concepts of Frequentist and Bayesian statistics, such as likelihoods and posteriors, the module will focus on four main challenges:

- How to obtain testable predictions from a given physical theory.
- How to infer the preferred parameter regions of a model from data.
- How to identify preferred models and design experiments to test them.
- How to handle large and complex data sets.

In particular, we will discuss Monte Carlo methods and machine learning techniques and apply them to practical examples.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Experience in programming with Python and Mathematica is desireable. Basic knowledge of theoretical particle physics and cosmology is helpful but not required.

**Literature**

- D. S. Sivia, “Data Analysis. A Bayesian Tutorial”
- G. Bohm, G. Zech, “Introduction to Statistics and Data Analysis for Physicists”, [https://www-library.desy.de/preparch/books/vstatmp_engl.pdf](https://www-library.desy.de/preparch/books/vstatmp_engl.pdf)
Module: Computational Methods for Particle Physics and Cosmology (Minor) [M-PHYS-106118]

Responsible: TT-Prof. Dr. Felix Kahlhöfer
Organisation: KIT Department of Physics
Part of: Minor in Physics: Experimental Astroparticle Physics
Minor in Physics: Theoretical Particle Physics

Credits: 6
Grading scale: pass/fail
Recurrence: Irregular
Duration: 1 term
Language: English
Level: 4
Version: 1

Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Competence Goal
Students know how to confront theoretical models with experimental data in order to identify preferred models and promising measurements. Students can use tools like FeynRules and MadGraph to calculate cross sections and generate events for processes beyond the Standard Model of particle physics. Students know how to infer model parameters from data using Markov chain Monte Carlos and perform a Bayesian model comparison. Students have some experience with machine learning and understand the range of possible applications of deep neural networks in particle physics and cosmology.

Content
The aim of this module is to explore modern methods for connecting theoretical models in particle physics and cosmology with data from experiments and observations. After a general introduction into the fundamental concepts of Frequentist and Bayesian statistics, such as likelihoods and posteriors, the module will focus on four main challenges:

- How to obtain testable predictions from a given physical theory.
- How to infer the preferred parameter regions of a model from data.
- How to identify preferred models and design experiments to test them.
- How to handle large and complex data sets.

In particular, we will discuss Monte Carlo methods and machine learning techniques and apply them to practical examples.

Workload
180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. preparation of the exercises (135 hours).

Recommendation
Experience in programming with Python and Mathematica is desireable. Basic knowledge of theoretical particle physics and cosmology is helpful but not required.

Literature

- D. S. Sivia, “Data Analysis. A Bayesian Tutorial”
4.39 Module: Computational Photonics, with ext. Exercises [M-PHYS-101933]

**Responsible:** Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-103090 - Computational Photonics, with ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-103089 - Computational Photonics, without ext. Exercises must not have been started.
3. The module M-PHYS-103193 - Computational Photonics, without ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students can use a computer to solve optical problems and can use a computer to visualize details of the light matter interaction, know different strategies to solve Maxwell’s equations on rigorous grounds, know how spatial symmetries and the arrangement of matter in space can be used to formulate Maxwell’s equations such that they are amenable for a numerical solution, can implement programs with a reasonable complexity by themselves, can use a computer to discuss and explore optical phenomena, and are familiar with basic computational strategies that emerge in photonics, but comparably in any other scientific discipline as well.

The student can independently work out the numerical implementation of algorithms that were not explicitly presented in the lecture. That requires understanding of basic computational strategies. The student is, therefore, able to transfer technical knowledge to new domains. The student can develop on its own novel algorithms to solve given problems in the field of computational photonics.

**Content**

- Transfer Matrix Method to describe the optical response from stratified media
- Finite Differences to characterize eigenmode in fiber waveguides
- Beam propagation method to describe the evolution of light in the realm of integrated optics
- Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D
- Mie Theory to describe the scattering of light from individual cylindrical or spherical objects
- Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems
- Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape
- Greens’ Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background
- Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**

Interest in theoretical physics, optics and electrodynamics. Moreover, interest in computational aspects is important.
**Literature**

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Principles of Optics" M. Born and E. Wolf
- “Light Scattering by Small Particles” H. C. van de Hulst

Specific references for the individual topics will be given during the lectures.
The lecture material that will be fully made available online.
M 4.40 Module: Computational Photonics, with ext. Exercises (Minor) [M-PHYS-103090]

**Responsible:** Prof. Dr. Carsten Rockstuhl  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Minor in Physics: Nanophysics  
- Minor in Physics: Optics and Photonics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-103089 - Computational Photonics, without ext. Exercises must not have been started.
2. The module M-PHYS-101933 - Computational Photonics, with ext. Exercises must not have been started.
3. The module M-PHYS-103193 - Computational Photonics, without ext. Exercises (Minor) must not have been started.

**Competence Goal**
The students can use a computer to solve optical problems and can use a computer to visualize details of the light matter interaction, know different strategies to solve Maxwell's equations on rigorous grounds, know how spatial symmetries and the arrangement of matter in space can be used to formulate Maxwell's equations such that they are amenable for a numerical solution, can implement programs with a reasonable complexity by themselves, can use a computer to discuss and explore optical phenomena, and are familiar with basic computational strategies that emerge in photonics, but comparably in any other scientific discipline as well.

The student can independently work out the numerical implementation of algorithms that were not explicitly presented in the lecture. That requires understanding of basic computational strategies. The student is, therefore, able to transfer technical knowledge to new domains. The student can develop on its own novel algorithms to solve given problems in the field of computational photonics.

**Content**

- Transfer Matrix Method to describe the optical response from stratified media  
- Finite Differences to characterize eigenmode in fiber waveguides  
- Beam propagation method to describe the evolution of light in the realm of integrated optics  
- Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D  
- Mie Theory to describe the scattering of light from individual cylindrical or spherical objects  
- Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems  
- Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape  
- Greens’ Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background  
- Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**
Interest in theoretical physics, optics and electrodynamics. Moreover, interest in computational aspects is important.
Literature

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Principles of Optics" M. Born and E. Wolf
- "Light Scattering by Small Particles" H. C. van de Hulst

Specific references for the individual topics will be given during the lectures.
The lecture material that will be fully made available online.
4 MODULES

Module: Computational Photonics, without ext. Exercises [M-PHYS-103089]

**M 4.41 Module: Computational Photonics, without ext. Exercises [M-PHYS-103089]**

**Responsible:** Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

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**Mandatory**

| T-PHYS-106131 | Computational Photonics, without ext. Exercises | 6 CR | Rockstuhl |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-101933 - Computational Photonics, with ext. Exercises must not have been started.
2. The module M-PHYS-103090 - Computational Photonics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-103193 - Computational Photonics, without ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students can use a computer to solve optical problems and can use a computer to visualize details of the light matter interaction, know different strategies to solve Maxwell’s equations on rigorous grounds, know how spatial symmetries and the arrangement of matter in space can be used to formulate Maxwell’s equations such that they are amenable for a numerical solution, can implement programs with a reasonable complexity by themselves, can use a computer to discuss and exploit optical phenomena, and are familiar with basic computational strategies that emerge in photonics, but comparably in any other scientific discipline as well.

**Content**

- Transfer Matrix Method to describe the optical response from stratified media
- Finite Differences to characterize eigenmode in fiber waveguides
- Beam propagation method to describe the evolution of light in the realm of integrated optics
- Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D
- Mie Theory to describe the scattering of light from individual cylindrical or spherical objects
- Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems
- Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape
- Greens’ Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background
- Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface

**Annotation**

For students of the KIT Faculty of Computer Science: The exams in this module have to be registered via admissions from ISS (KIT Faculty of Computer Science). For this, an e-mail with matriculation number and name of the desired exam to Beratung-informatik@informatik.kit.edu is sufficient.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (135 hours).

**Recommendation**

Interest in theoretical physics, optics and electrodynamics. Moreover, interest in computational aspects is important.
Literature

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Principles of Optics" M. Born and E. Wolf
- "Light Scattering by Small Particles" H. C. van de Hulst

Specific references for the individual topics will be given during the lectures.
The lecture material that will be fully made available online.
Module: Computational Photonics, without ext. Exercises (Minor) [M-PHYS-103193]

**Responsible:** Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Optics and Photonics

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**Mandatory**

| T-PHYS-106326 | Computational Photonics, without ext. Exercises (Minor) | 6 CR | Rockstuhl |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-101933 - Computational Photonics, with ext. Exercises must not have been started.
2. The module M-PHYS-103090 - Computational Photonics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-103089 - Computational Photonics, without ext. Exercises must not have been started.

**Competence Goal**
The students can use a computer to solve optical problems and can use a computer to visualize details of the light matter interaction, know different strategies to solve Maxwell's equations on rigorous grounds, know how spatial symmetries and the arrangement of matter in space can be used to formulate Maxwell's equations such that they are amenable for a numerical solution, can implement programs with a reasonable complexity by themselves, can use a computer to discuss and explore optical phenomena, and are familiar with basic computational strategies that emerge in photonics, but comparably in any other scientific discipline as well.

**Content**

- Transfer Matrix Method to describe the optical response from stratified media
- Finite Differences to characterize eigenmode in fiber waveguides
- Beam propagation method to describe the evolution of light in the realm of integrated optics
- Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D
- Mie Theory to describe the scattering of light from individual cylindrical or spherical objects
- Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems
- Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape
- Greens' Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background
- Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of lecture and completion of exercises (135 hours).

**Recommendation**
Interest in theoretical physics, optics and electrodynamics. Moreover, interest in computational aspects is important.
Literature

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Principles of Optics" M. Born and E. Wolf
- "Light Scattering by Small Particles" H. C. van de Hulst

Specific references for the individual topics will be given during the lectures.
The lecture material that will be fully made available online.
4.43 Module: Condensed Matter Theory I, Fundamentals [M-PHYS-102054]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter Theory (Required Condensed Matter Theory)  
Second Major in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-102559 | Condensed Matter Theory I, Fundamentals | 8 CR | Garst, Mirlin, Shnirman |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102051 - Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) must not have been started.
2. The module M-PHYS-102052 - Condensed Matter Theory I, Fundamentals (Minor) must not have been started.
3. The module M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics must not have been started.

**Competence Goal**

Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a limited class of problems in the field of condensed matter physics.

**Content**

Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in an external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.
**Literature**

- C. Kittel, *Quantum Theory of Solids*.
- A. A. Abrikosov, *Fundamentals of the Theory of Metals*
Module: Condensed Matter Theory I, Fundamentals (Minor) [M-PHYS-102052]

**Responsible:** Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Condensed Matter Theory

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**Competence Certificate**

Course work, ungraded.

The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102051 - Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) must not have been started.
2. The module M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics must not have been started.
3. The module M-PHYS-102054 - Condensed Matter Theory I, Fundamentals must not have been started.

**Competence Goal**

Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a limited class of problems in the field of condensed matter physics.

**Content**

Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in an external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.

**Literature**

- C. Kittel, Quantum Theory of Solids.
- A. A. Abrikosov, Fundamentals of the Theory of Metals
### 4.45 Module: Condensed Matter Theory I, Fundamentals and Advanced Topics [M-PHYS-102053]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
Prof. Dr. Alexander Shnirman  

**Organisation:** KIT Department of Physics  

**Part of:**  
- Major in Physics: Condensed Matter Theory (Required Condensed Matter Theory)  
- Second Major in Physics: Condensed Matter Theory

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<td>Each winter term</td>
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<td>Condensed Matter Theory I, Fundamentals and Advanced Topics</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102051 - Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) must not have been started.
2. The module M-PHYS-102052 - Condensed Matter Theory I, Fundamentals (Minor) must not have been started.
3. The module M-PHYS-102054 - Condensed Matter Theory I, Fundamentals must not have been started.

**Competence Goal**

Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a broader class of problems in the field of condensed matter physics.

**Content**

Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in the external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction;
- Superconductivity: BCS theory, electrodynamics of superconductors, Ginzburg-Landau theory.

**Workload**

360 hours consisting of attendance time (90 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (270 hours)

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.
Literature

- C. Kittel, Quantum Theory of Solids.
- A. A. Abrikosov, Fundamentals of the Theory of Metals
Module: Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) [M-PHYS-102051]

Responsible:
Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

Organisation:
KIT Department of Physics

Part of:
Minor in Physics: Condensed Matter Theory

Credits: 12
Grading scale: pass/fail
Recurrence: Each winter term
Duration: 1 term
Language: English
Level: 4
Version: 1

Mandatory

T-PHYS-102556 Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) 12 CR Garst, Mirlin, Shnirman

Competence Certificate
Course work, ungraded.
The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102052 - Condensed Matter Theory I, Fundamentals (Minor) must not have been started.
2. The module M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics must not have been started.
3. The module M-PHYS-102054 - Condensed Matter Theory I, Fundamentals must not have been started.

Competence Goal
Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a broader class of problems in the field of condensed matter physics.

Content
Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in the external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction;
- Superconductivity: BCS theory, electrodynamics of superconductors, Ginzburg-Landau theory.

Workload
360 hours consisting of attendance time (90 hours), wrap-up of the lecture and work on the exercises (270 hours).

Recommendation
Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.

Literature
- C. Kittel, Quantum Theory of Solids.
- A. A. Abrikosov, Fundamentals of the Theory of Metals
Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals [M-PHYS-102313]

**Responsible:**
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- PD Dr. Boris Narozhnyy
- Prof. Dr. Jörg Schmalian

**Organisation:**
KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-104591 | Condensed Matter Theory II: Many-Body Systems, Fundamentals | 8 CR |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-102312 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-102314 - Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor) must not have been started.
4. The module M-PHYS-103331 - Condensed Matter Theory II: Many-Body Theory, selected topics must not have been started.

**Competence Goal**

Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a limited class of advanced problems in the field of condensed matter physics.

**Content**

Estimated structure of the lecture:

1. Green's functions for non-interacting particles
2. Many-body Green's functions
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)
5. Functional formulation of many-body theory
6. Superconducting systems
7. Non-equilibrium systems and Keldysh technique
8. Many-body systems in one dimension

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**

In general this lecture should be attended after Theory of Condensed Matter I.
Literature

- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischen Physik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle systems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor) [M-PHYS-102314]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Condensed Matter Theory

**Credits:** 8  
**Grading scale:** pass/fail  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** English  
**Level:** 4  
**Version:** 1

**Mandatory**

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**Competence Certificate**
Course work, ungraded.
The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-102312 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals must not have been started.
4. The module M-PHYS-103331 - Condensed Matter Theory II: Many-Body Theory, selected topics must not have been started.

**Competence Goal**
Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a limited class of advanced problems in the field of condensed matter physics.

**Content**
Estimated structure of the lecture:

1. Green's functions for non-interacting particles
2. Many-body Green's functions
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)
5. Functional formulation of many-body theory
6. Superconducting systems
7. Non-equilibrium systems and Keldysh technique
8. Many-body systems in one dimension

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**
In general this lecture should be attended after Theory of Condensed Matter I.
Literature

- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischen Physik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle systems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics [M-PHYS-102308]

Responsibility:
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- PD Dr. Boris Narozhnyy
- Prof. Dr. Jörg Schmalian

Organisation:
- KIT Department of Physics

Part of:
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Condensed Matter Theory

Credits: 12
Grading scale: Grade to a tenth
Recurrence: Each summer term
Duration: 1 term
Language: English
Level: 4
Version: 1

Mandatory

T-PHYS-102560 Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics

12 CR Garst, Mirlin, Narozhnyy, Schmalian

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102312 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor) must not have been started.
2. The module M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals must not have been started.
3. The module M-PHYS-102314 - Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor) must not have been started.
4. The module M-PHYS-103331 - Condensed Matter Theory II: Many-Body Theory, selected topics must not have been started.

Competence Goal
Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a broader class of advanced problems in the field of condensed matter physics.

Content
Estimated structure of the lecture:

1. Green's functions for non-interacting particles
2. Many-body Green's functions
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)
5. Functional formulation of many-body theory
6. Superconducting systems
7. Non-equilibrium systems and Keldysh technique
8. Many-body systems in one dimension
9. Kondo effect
10. Strongly correlated electrons: Hubbard model and Mott metal-insulator transition
11. Introduction to mesoscopic physics

Workload
360 hours consisting of attendance time (90 hours), follow-up of the lecture incl. exam preparation and working on the exercises (270 hours)
Recommendation
In general this lecture should be attended after Theory of Condensed Matter I.

Literature

- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischen Physik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle systems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor) [M-PHYS-102312]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian  

**Organisation:** KIT Department of Physics  

**Part of:** Minor in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-102562 | Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics (Minor) | 12 CR | Garst, Mirlin, Narozhnyy, Schmalian |

**Competence Certificate**  
Course work, ungraded.  
The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals must not have been started.
3. The module M-PHYS-102314 - Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor) must not have been started.
4. The module M-PHYS-103331 - Condensed Matter Theory II: Many-Body Theory, selected topics must not have been started.

**Competence Goal**

Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a broader class of advanced problems in the field of condensed matter physics.

**Content**

Estimated structure of the lecture:

1. Green's functions for non-interacting particles  
2. Many-body Green's functions  
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)  
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)  
5. Functional formulation of many-body theory  
6. Superconducting systems  
7. Non-equilibrium systems and Keldysh technique  
8. Many-body systems in one dimension  
9. Kondo effect  
10. Strongly correlated electrons: Hubbard model and Mott metal-insulator transition  
11. Introduction to mesoscopic physics

**Workload**

360 hours consisting of attendance time (90 hours), wrap-up of the lecture and work on the exercises (270 hours).

**Recommendation**

In general this lecture should be attended after Theory of Condensed Matter I.
Literature

- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischen Physik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle systems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
4.51 Module: Condensed Matter Theory II: Many-Body Theory, selected topics [M-PHYS-103331]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-102312 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals must not have been started.
4. The module M-PHYS-102314 - Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor) must not have been started.

**Competence Goal**

Acquiring basic knowledge about advanced field-theoretical approaches of condensed matter physics.

**Content**

Estimated structure of the lecture:

- Green's functions for non-interacting particles
- Many-body Green's functions
- Feynman diagrams

**Workload**

60 hours consisting of attendance time (15 hours), wrap-up of the lecture incl. exam preparation (45 hours).

**Recommendation**

In general this lecture should be attended after Theory of Condensed Matter I.
Literature

- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischen Physik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle systems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
4.52 Module: Detectors for Particle and Astroparticle Physics, with ext. Exercises [M-PHYS-102121]

**Responsible:** PD Dr. Frank Hartmann
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

**Credits** 8

**Grading scale** Grade to a tenth

**Recurrence** Each winter term

**Duration** 1 term

**Language** English

**Level** 4

**Version** 1

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102119 - Detectors for Particle and Astroparticle Physics, without ext. Exercises must not have been started.
2. The module M-PHYS-102120 - Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102122 - Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Advanced study in one area of experimental particle and astroparticle physics. Students learn experimental aspects of measuring particle properties. Thus, they learn the basics for a detailed analysis of experimental data, the operation of complex experiments and the work with modern particle detectors. The practical exercises introduce the students to experimental work with detectors in teams. In extended exercises, basic principles of sensors and their design optimization are simulated on the computer.

**Content**

Interaction of electrons, photons, muons, charged and neutral hadrons with matter; electronic detection of particle radiation and measurement of deposited energy and particle identification; gas-filled detectors, scintillators, photomultipliers, silicon detectors, electromagnetic and hadronic calorimeters, detector systems, triggers and data acquisition, reconstruction of physical objects in detector systems, applications outside basic research.

**Workload**

240 hours, of which attendance time (60 hours). The remaining hours are used for preparation for the experiments, preparation of practical protocols, follow-up of the lecture material and preparation for the examination (180 hours).

**Recommendation**

Basic knowledge of experimental nuclear and particle physics, e.g. from the lecture Modern Experimental Physics III in the bachelor's program in physics. Basic knowledge of electronics is also helpful.
Literature

- C. Grupen: Particle Detectors, Cambridge University Press (2011)
- Particle Data Group: The Review of Particle Physics
4.53 Module: Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor) [M-PHYS-102122]

**Responsible:** PD Dr. Frank Hartmann  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**  
- Minor in Physics: Experimental Particle Physics  
- Minor in Physics: Experimental Astroparticle Physics

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**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102119 - Detectors for Particle and Astroparticle Physics, without ext. Exercises must not have been started.
2. The module M-PHYS-102120 - Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102121 - Detectors for Particle and Astroparticle Physics, with ext. Exercises must not have been started.

**Competence Goal**

Advanced study in one area of experimental particle and astroparticle physics. Students learn experimental aspects of measuring particle properties. Thus, they learn the basics for a detailed analysis of experimental data, the operation of complex experiments and the work with modern particle detectors. The practical exercises introduce the students to experimental work with detectors in teams. In extended exercises, basic principles of sensors and their design optimization are simulated on the computer.

**Content**

Interaction of electrons, photons, muons, charged and neutral hadrons with matter; electronic detection of particle radiation and measurement of deposited energy and particle identification; gas-filled detectors, scintillators, photomultipliers, silicon detectors, electromagnetic and hadronic calorimeters, detector systems, triggers and data acquisition, reconstruction of physical objects in detector systems, applications outside basic research.

**Workload**

240 hours, of which attendance time (60 hours). The remaining hours are for preparation for the experiments, preparation of practical protocols and follow-up of the lecture material (180 hours).

**Recommendation**

Basic knowledge of experimental nuclear and particle physics, e.g. from the lecture Modern Experimental Physics III in the bachelor's program in physics. Basic knowledge of electronics is also helpful.

**Literature**

- C. Grupen: Particle Detectors, Cambridge University Press (2011)  
- Particle Data Group: The Review of Particle Physics  
Module: Detectors for Particle and Astroparticle Physics, without ext. Exercises [M-PHYS-102119]

**Responsible:** PD Dr. Frank Hartmann  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Mandatory**

| T-PHYS-104453 | Detectors for Particle and Astroparticle Physics, without ext. Exercises | 6 CR | Hartmann, Husemann, Klute |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102120 - Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102121 - Detectors for Particle and Astroparticle Physics, with ext. Exercises must not have been started.
3. The module M-PHYS-102122 - Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**  
Advanced study in one area of experimental particle and astroparticle physics. Students learn experimental aspects of measuring particle properties. Thus, they learn the basics for a detailed analysis of experimental data, the operation of complex experiments and the work with modern particle detectors. The practical exercises introduce the students to experimental work with detectors in teams.

**Content**  
Interaction of electrons, photons, muons, charged and neutral hadrons with matter; electronic detection of particle radiation and measurement of deposited energy and particle identification; gas-filled detectors, scintillators, photomultipliers, silicon detectors, electromagnetic and hadronic calorimeters, detector systems, triggers and data acquisition, reconstruction of physical objects in detector systems, applications outside basic research.

**Workload**  
180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and processing of the exercises and the internship (135 hours).

**Recommendation**  
Basic knowledge of experimental nuclear and particle physics, e.g. from the lecture Modern Experimental Physics III in the bachelor's program in physics. Basic knowledge of electronics is also helpful.

**Literature**

- C. Grupen: Particle Detectors, Cambridge University Press (2011)
- Particle Data Group: The Review of Particle Physics
Module: Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) [M-PHYS-102120]

Responsibility: PD Dr. Frank Hartmann
Prof. Dr. Markus Klute

Organisation: KIT Department of Physics

Part of: Minor in Physics: Experimental Particle Physics
Minor in Physics: Experimental Astroparticle Physics

Credits: 6
Grading scale: pass/fail
Recurrence: Each winter term
Duration: 1 term
Language: English
Level: 4
Version: 1

Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102119 - Detectors for Particle and Astroparticle Physics, without ext. Exercises must not have been started.
2. The module M-PHYS-102121 - Detectors for Particle and Astroparticle Physics, with ext. Exercises must not have been started.
3. The module M-PHYS-102122 - Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor) must not have been started.

Competence Goal
Advanced study in one area of experimental particle and astroparticle physics. Students learn experimental aspects of measuring particle properties. Thus, they learn the basics for a detailed analysis of experimental data, the operation of complex experiments and the work with modern particle detectors. The practical exercises introduce the students to experimental work with detectors in teams.

Content
Interaction of electrons, photons, muons, charged and neutral hadrons with matter; electronic detection of particle radiation and measurement of deposited energy and particle identification; gas-filled detectors, scintillators, photomultipliers, silicon detectors, electromagnetic and hadronic calorimeters, detector systems, triggers and data acquisition, reconstruction of physical objects in detector systems, applications outside basic research.

Workload
180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. working on the exercises and the internship (135 hours).

Recommendation
Basic knowledge of experimental nuclear and particle physics, e.g. from the lecture Modern Experimental Physics III in the bachelor's program in physics. Basic knowledge of electronics is also helpful.

Literature

- C. Grupen: Particle Detectors, Cambridge University Press (2011)
- Particle Data Group: The Review of Particle Physics
4.56 Module: Electron Microscopy I, with Exercises [M-PHYS-102989]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Major in Physics: Nanophysics (Elective Nanophysics)  
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none, the lectures Electron Microscopy I and II are independent of each other

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102990 - Electron Microscopy I, without Exercises must not have been started.
2. The module M-PHYS-102991 - Electron Microscopy I, with Exercises (Minor) must not have been started.

**Competence Goal**

From analogies to light microscopy, students will understand parallels and differences between light microscopy and transmission electron microscopy (TEM) as well as image formation in the transmission electron microscope. Students will be able to describe and explain the interaction between high energy electrons and solids (kinematic diffraction theory and its limitations in electron-solid interaction, dynamic diffraction theory). Using theoretical concepts for dynamic electron diffraction and the imaging process, interpret TEM images (What contrasts arise for perfect solids and defects in solids?). Through application examples from solid state physics and materials research, students will learn and understand the applications and limitations of TEM.

In the practical exercises the theoretical concepts from the lecture as well as TEM imaging modes will be visualized, practiced and deepened by working in small groups.

**Content**

Transmission electron microscopy (TEM), high-resolution TEM, scanning transmission electron microscopy, kinematic and dynamic electron diffraction in the solid state, TEM contrast generation with application examples from materials and solid state physics, electron holography, transmission electron microscopy with phase plates.

**Workload**

240 hours, of which attendance time (60 hours). The remaining hours are for preparation for the experiments, preparation of practical protocols, wrap-up of the lecture material and preparation for the examination (180 hours).

**Recommendation**

Basic knowledge of optics, solid state physics, materials physics or materials science, quantum mechanics

**Literature**

L. Reimer, H. Kohl, Transmission Electron Microscopy, Springer Verlag
4.57 Module: Electron Microscopy I, with Exercises (Minor) [M-PHYS-102991]

- **Responsible:** TT-Prof. Dr. Yolita Eggeler
- **Organisation:** KIT Department of Physics
- **Part of:**
  - Minor in Physics: Condensed Matter
  - Minor in Physics: Nanophysics

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**Mandatory**

| T-PHYS-105968 | Electron Microscopy I, with Exercises (Minor) | 8 CR | Eggeler |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
one, the lectures Electron Microscopy I and II are independent of each other

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102989 - Electron Microscopy I, with Exercises must not have been started.
2. The module M-PHYS-102990 - Electron Microscopy I, without Exercises must not have been started.

**Competence Goal**
From analogies to light microscopy, students will understand parallels and differences between light microscopy and transmission electron microscopy (TEM) as well as image formation in the transmission electron microscope. Students will be able to describe and explain the interaction between high energy electrons and solids (kinematic diffraction theory and its limitations in electron-solid interaction, dynamic diffraction theory). Using theoretical concepts for dynamic electron diffraction and the imaging process, interpret TEM images (What contrasts arise for perfect solids and defects in solids?). Through application examples from solid state physics and materials research, students will learn and understand the applications and limitations of TEM.

In the practical exercises the theoretical concepts from the lecture as well as TEM imaging modes will be visualized, practiced and deepened by working in small groups.

**Content**
Transmission electron microscopy (TEM), high-resolution TEM, scanning transmission electron microscopy, kinematic and dynamic electron diffraction in the solid state, TEM contrast generation with application examples from materials and solid state physics, electron holography, transmission electron microscopy with phase plates.

**Workload**
240 hours, of which attendance time (60 hours). The remaining hours are used for preparation for the experiments, preparation of practical protocols and wrap-up of the lecture material (180 hours).

**Recommendation**
Basic knowledge of optics, solid state physics, materials physics or materials science, quantum mechanics

**Literature**
L. Reimer, H. Kohl, Transmission Electron Microscopy, Springer Verlag
Module: Electron Microscopy I, without Exercises [M-PHYS-102990]

**Responsible:** TT-Prof. Dr. Yolita Eggeler

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Mandatory**

| T-PHYS-105967 | Electron Microscopy I, without Exercises | 4 CR | Eggeler |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none, the lectures Electron Microscopy I and II are independent of each other

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102989 - Electron Microscopy I, with Exercises must not have been started.
2. The module M-PHYS-102991 - Electron Microscopy I, with Exercises (Minor) must not have been started.

**Competence Goal**

From analogies to light microscopy, students will understand parallels and differences between light microscopy and transmission electron microscopy (TEM) as well as image formation in the transmission electron microscope. Students will be able to describe and explain the interaction between high energy electrons and solids (kinematic diffraction theory and its limitations in electron-solid interaction, dynamic diffraction theory). Using theoretical concepts for dynamic electron diffraction and the imaging process, interpret TEM images (What contrasts arise for perfect solids and defects in solids?). Through application examples from solid state physics and materials research, students will learn and understand the applications and limitations of TEM.

**Content**

Transmission electron microscopy (TEM), high-resolution TEM, scanning transmission electron microscopy, kinematic and dynamic electron diffraction in the solid state, TEM contrast generation with application examples from materials and solid state physics, electron holography, transmission electron microscopy with phase plates.

**Workload**

120 hours, of which attendance time (30 hours). The remaining hours are used for wrap-up of the lecture material and preparation for the exam (90 hours).

**Recommendation**

Basic knowledge of optics, solid state physics, materials physics or materials science, quantum mechanics

**Literature**

L. Reimer, H. Kohl, Transmission Electron Microscopy, Springer Verlag
M 4.59 Module: Electron Microscopy II, with Exercises [M-PHYS-102227]

Responsible: TT-Prof. Dr. Yolita Eggeler
Organisation: KIT Department of Physics
Part of: Major in Physics: Condensed Matter (Elective Condensed Matter)
Major in Physics: Nanophysics (Elective Nanophysics)
Second Major in Physics: Condensed Matter (Elective Condensed Matter)
Second Major in Physics: Nanophysics (Elective Nanophysics)

Credits 8
Grading scale Grade to a tenth
Recurrence Each summer term
Duration 1 term
Language German/English
Level 4
Version 1

Mandatory
T-PHYS-102349 Electron Microscopy II, with Exercises 8 CR Eggeler

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102844 - Electron Microscopy II, without Exercises must not have been started.
2. The module M-PHYS-103172 - Electron Microscopy II, with Exercises (Minor) must not have been started.

Competence Goal
Students should be able to understand and explain image formation in scanning electron microscopy and scanning ion microscopy, nanostructuring with focused ion beams, and analytical procedures in electron microscopy (chemical analysis, electronic properties). On the basis of application examples from materials and solid-state physics, students should be able to recognize possible applications and limitations of the methods. The students should be able to assess which method(s) is (are) suitable for specific problems from micro- and nanocharacterization.

In the practical exercises, the theoretical concepts from the lecture as well as imaging modes in scanning electron microscopy and scanning ion microscopy are visualized, practiced and deepened by working in small groups. Students should be able to adjust a scanning electron microscope for simple applications.

Content
Scanning electron microscopy, imaging and patterning with focused ion beams, analytical techniques in electron microscopy (energy dispersive X-ray spectroscopy and electron energy loss spectroscopy).

Workload
240 hours, of which attendance time (60 hours). The remaining hours are for preparation for the experiments, preparation of practical protocols, wrap-up of the lecture material and preparation for the examination (180 hours).

Recommendation
Basic knowledge of optics, solid state physics, materials physics and materials science

Literature
- L. Reimer, Scanning Electron Microscopy, Springer
4.60 Module: Electron Microscopy II, with Exercises (Minor) [M-PHYS-103172]

**Responsible:** TT-Prof. Dr. Yolita Eggeler

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Nanophysics

**Credits:** 8
**Grading scale:** pass/fail
**Recurrence:** Each summer term
**Duration:** 1 term
**Language:** German/English
**Level:** 4
**Version:** 1

**Mandatory**

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102844 - Electron Microscopy II, without Exercises must not have been started.
2. The module M-PHYS-102227 - Electron Microscopy II, with Exercises must not have been started.

**Competence Goal**
Students should be able to understand and explain image formation in scanning electron microscopy and scanning ion microscopy, nanostructuring with focused ion beams, and analytical procedures in electron microscopy (chemical analysis, electronic properties). On the basis of application examples from materials and solid-state physics, students should be able to recognize possible applications and limitations of the methods. The students should be able to assess which method(s) is (are) suitable for specific problems from micro- and nanocharacterization.

In the practical exercises, the theoretical concepts from the lecture as well as imaging modes in scanning electron microscopy and scanning ion microscopy are visualized, practiced and deepened by working in small groups. Students should be able to adjust a scanning electron microscope for simple applications.

**Content**
Scanning electron microscopy, imaging and patterning with focused ion beams, analytical techniques in electron microscopy (energy dispersive X-ray spectroscopy and electron energy loss spectroscopy).

**Workload**
240 hours, of which attendance time (60 hours). The remaining hours are used for preparation for the experiments, preparation of practical protocols and wrap-up of the lecture material (180 hours).

**Recommendation**
Basic knowledge of optics, solid state physics, materials physics and materials science

**Literature**

- L. Reimer, Scanning Electron Microscopy, Springer
Module: Electron Microscopy II, without Exercises [M-PHYS-102844]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Major in Physics: Nanophysics (Elective Nanophysics)  
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102227 - Electron Microscopy II, with Exercises must not have been started.
2. The module M-PHYS-103172 - Electron Microscopy II, with Exercises (Minor) must not have been started.

**Competence Goal**

Students should be able to understand and explain image formation in scanning electron microscopy and scanning ion microscopy, nanostructuring with focused ion beams, and analytical procedures in electron microscopy (chemical analysis, electronic properties). On the basis of application examples from materials and solid-state physics, students should be able to recognize possible applications and limitations of the methods. The students should be able to assess which method(s) is (are) suitable for specific problems from micro- and nanocharacterization.

**Content**

Scanning electron microscopy, imaging and patterning with focused ion beams, analytical techniques in electron microscopy (energy dispersive X-ray spectroscopy and electron energy loss spectroscopy).

**Workload**

120 hours, of which attendance time (30 hours). The remaining hours are used for wrap-up of the lecture material and preparation for the exam (90 hours).

**Recommendation**

Basic knowledge of optics, solid state physics, materials physics and materials science

**Literature**

- L. Reimer, Scanning Electron Microscopy, Springer  
Module: Electronic Properties of Solids I, with Exercises [M-PHYS-102089]

Responsible: Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

Organisation: KIT Department of Physics

Part of:  
- Major in Physics: Condensed Matter (Required Condensed Matter)  
- Major in Physics: Nanophysics (Required Elective Nanophysics)  
- Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)

Credits 10  
Grading scale Grade to a tenth  
Recurrence Each winter term  
Duration 1 term  
Language English  
Level 4  
Version 1

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Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102087 - Electronic Properties of Solids I, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102090 - Electronic Properties of Solids I, without Exercises must not have been started.

Competence Goal
Students will be familiar with the most common experimental methods for studying the electronic properties of condensed matter and some of the key theoretical concepts that underlie them. They master the basic tools for studying and understanding heat transport, scattering mechanisms, phase transitions, and magnetism. Exercises will reinforce the acquired knowledge and apply it to classical condensed matter problems.

Content
- Metal and insulators: Band structure, Fermi surface
- Electronic and heat transport - scattering mechanisms
- Phase transitions: Landau theory, critical exponents
- Atomic magnetism and magnetic interactions
- Magnetic structures, dynamics

Annotation
The course will be given in English. Questions and discussions in German are welcome as well.

Workload
300 hours consisting of attendance time (75 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (225 hours)

Recommendation
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics and statistical physics is assumed.
Literature

- R. Gross, A. Marx, Festkörperphysik
- N. W. Ashcroft, N. D. Mermin: Festkörperphysik
- H. Ibach, H. Lüth: Festkörperphysik
- C. Kittel: Einführung in die Festkörperphysik
- S. Blundell, Magnetism in Condensed Matter
Module: Electronic Properties of Solids I, with Exercises (Minor) [M-PHYS-102087]

Responsible: Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

Organisation: KIT Department of Physics  
Part of: Minor in Physics: Condensed Matter  
Minor in Physics: Nanophysics

Credits 10  
Grading scale pass/fail  
Recurrence Each winter term  
Duration 1 term  
Language English  
Level 4  
Version 1

Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102089 - Electronic Properties of Solids I, with Exercises must not have been started.
2. The module M-PHYS-102090 - Electronic Properties of Solids I, without Exercises must not have been started.

Competence Goal
Students will be familiar with the most common experimental methods for studying the electronic properties of condensed matter and some of the key theoretical concepts that underlie them. They master the basic tools for studying and understanding heat transport, scattering mechanisms, phase transitions, and magnetism. Exercises will reinforce the acquired knowledge and apply it to classical condensed matter problems.

Content
- Metal and insulators: Band structure, Fermi surface  
- Electronic and heat transport - scattering mechanisms  
- Phase transitions: Landau theory, critical exponents  
- Atomic magnetism and magnetic interactions  
- Magnetic structures, dynamics

Annotation
The course will be given in English. Questions and discussions in German are welcome as well.

Workload
300 hours consisting of attendance time (75 hours), wrap-up of the lecture and preparation of the exercises (225 hours).

Recommendation
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics and statistical physics is assumed.

Literature
- R. Gross, A. Marx, Festkörperphysik  
- N. W. Ashcroft, N. D. Mermin: Festkörperphysik  
- H. Ibach, H. Lüth: Festkörperphysik  
- C. Kittel: Einführung in die Festkörperphysik  
- S. Blundell, Magnetism in Condensed Matter
Module: Electronic Properties of Solids I, without Exercises [M-PHYS-102090]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Condensed Matter (Required Condensed Matter)  
- Major in Physics: Nanophysics (Required Elective Nanophysics)  
- Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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<td>8 CR Le Tacon, Wernsdorfer, Wulfhekel</td>
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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102087 - Electronic Properties of Solids I, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102089 - Electronic Properties of Solids I, with Exercises must not have been started.

**Competence Goal**  
Students will be familiar with the most common experimental methods for studying the electronic properties of condensed matter and some of the key theoretical concepts that underlie them. They will master the basic tools for studying and understanding heat transport, scattering mechanisms, phase transitions, and magnetism.

**Content**  
- Metal and insulators: Band structure, Fermi surface
- Electronic and heat transport - scattering mechanisms
- Phase transitions: Landau theory, critical exponents
- Atomic magnetism and magnetic interactions
- Magnetic structures, dynamics

**Annotation**  
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**  
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation (180 hours)

**Recommendation**  
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics and statistical physics is assumed.

**Literature**  
- R. Gross, A. Marx, Festkörperphysik
- N. W. Ashcroft, N. D. Mermin: Festkörperphysik
- H. Ibach, H. Lüth: Festkörperphysik
- C. Kittel: Einführung in die Festkörperphysik
- S. Blundell, Magnetism in Condensed Matter
4.65 Module: Electronic Properties of Solids II, with Exercises [M-PHYS-102108]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Dr. Johannes Rotzinger  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Nanophysics (Elective Nanophysics)  
Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
Second Major in Physics: Nanophysics (Elective Nanophysics)

**Credits:** 8  
**Grading scale:** Grade to a tenth  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** English  
**Level:** 4  
**Version:** 1

**Mandatory**

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Le Tacon, Rotzinger, Ustinov, Wernsdorfer

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102106 - Electronic Properties of Solids II, with Exercises (Minor) must not have been started.  
2. The module M-PHYS-102109 - Electronic Properties of Solids II, without Exercises must not have been started.

**Competence Goal**  
Students know the physical properties of superconductivity, a thermodynamic state of the electronic system of solids. They understand classical and modern experimental findings as well as basic theoretical models, such as the concept of the energy gap or the quasiparticle, which is also commonly used outside superconductivity. They apply the acquired knowledge to specific problems. The students are able to familiarize themselves with current literature on the subject of superconductivity.

**Content**  
Foundations of superconductivity: thermodynamics, electrodynamics, flux quantization, Ginzburg-Landau theory, BCS theory, vortices, tunnel junctions, Josephson junctions, SQUIDs, superconducting electronics, superconducting qubits.

**Annotation**  
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**  
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

**Recommendation**  
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

Module: Electronic Properties of Solids II, with Exercises (Minor) [M-PHYS-102106]

**Responsible:**
Prof. Dr. Matthieu Le Tacon  
Dr. Johannes Rotzinger  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:**
KIT Department of Physics

**Part of:**
Minor in Physics: Condensed Matter  
Minor in Physics: Nanophysics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102108 - Electronic Properties of Solids II, with Exercises must not have been started.
2. The module M-PHYS-102109 - Electronic Properties of Solids II, without Exercises must not have been started.

**Competence Goal**
Students know the physical properties of superconductivity, a thermodynamic state of the electronic system of solids. They understand classical and modern experimental findings as well as basic theoretical models, such as the concept of the energy gap or the quasiparticle, which is also commonly used outside superconductivity. They apply the acquired knowledge to specific problems. The students are able to familiarize themselves with current literature on the subject of superconductivity.

**Content**
Foundations of superconductivity: thermodynamics, electrodynamics, flux quantization, Ginzburg-Landau theory, BCS theory, vortices, tunnel junctions, Josephson junctions, SQUIDs, superconducting electronics, superconducting qubits.

**Annotation**
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Dr. Johannes Rotzinger  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Nanophysics (Elective Nanophysics)  
Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102106 - Electronic Properties of Solids II, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102108 - Electronic Properties of Solids II, with Exercises must not have been started.

**Competence Goal**

Students know the physical properties of superconductivity, a thermodynamic state of the electronic system of solids. They understand classical and modern experimental findings as well as basic theoretical models, such as the concept of the energy gap or the quasiparticle, which is also commonly used outside of superconductivity. Students are able to familiarize themselves with current literature on superconductivity.

**Content**

Foundations of superconductivity: thermodynamics, electrodynamics, flux quantization, Ginzburg-Landau theory, BCS theory, vortices, tunnel junctions, Josephson junctions, SQUIDs, superconducting electronics, superconducting qubits.

**Annotation**

The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**

120 hours consisting of attendance time (30 hours), wrap-up of the lecture incl. exam preparation (90 hours)

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

4.68 Module: Electronics for Physicists [M-PHYS-102184]

**Responsibility:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
Non-Physics Elective

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**Mandatory**

| T-PHYS-104479 | Electronics for Physicists | 10 CR | Rabbertz, Simon |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor) must not have been started.
2. The module M-PHYS-102179 - Electronics for Physicists: Analog Electronics must not have been started.
3. The module M-PHYS-102182 - Electronics for Physicists: Digital Electronics must not have been started.
4. The module M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor) must not have been started.
5. The module M-PHYS-102185 - Electronics for Physicists (Minor) must not have been started.

**Competence Goal**

Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics.

Providing a basic understanding of analog and digital electronics and their application in experimental physics. Understanding of analog and digital circuits and their construction and testing. Use of modern measurement equipment such as digital oscilloscopes and evaluation of the measurement results obtained in comparison with circuit simulations of analog electronics. Use and programming of modern digital electronics hardware (FPGAs) and evaluation of the results obtained.

**Content**

Introduction to analog and digital electronics:

- The "electronics chain" of detectors in experimental physics
- Fundamentals, linear networks, passive components, filters
- Elementary circuit analysis and simulation
- Operational amplifiers, Bipolar and field effect transistors
- Basic circuits with one and two transistors
- Number systems, circuit algebra, logic devices, flip-flops, memories
- Analog-to-digital converters
- Programmable electronics: CPLDs, FPGAs
- Packaging and interconnection technology
- Noise in detector systems

**Workload**

300 hours consisting of attendance time (75 hours), follow-up of the lecture incl. exam preparation and processing of the exercises and the internship (225 hours).

**Recommendation**

Interest in electronics
**Literature**
Literature will be mentioned in the lecture. A script will also be provided.
4.69 Module: Electronics for Physicists (Minor) [M-PHYS-102185]

Responsible: PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

Organisation: KIT Department of Physics
Part of: Minor in Physics: Experimental Particle Physics  
Minor in Physics: Experimental Astroparticle Physics

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| T-PHYS-104480 | Electronics for Physicists (Minor) | 10 CR | Rabbertz, Simon |

Competence Certificate
The course credit is achieved through successful participation in the practical exercises. The details will be announced in the first lecture or at the first practical exercises.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor) must not have been started.
2. The module M-PHYS-102179 - Electronics for Physicists: Analog Electronics must not have been started.
3. The module M-PHYS-102182 - Electronics for Physicists: Digital Electronics must not have been started.
4. The module M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor) must not have been started.
5. The module M-PHYS-102184 - Electronics for Physicists must not have been started.

Competence Goal
Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics. Providing a basic understanding of analog and digital electronics and their application in experimental physics. Understanding of analog and digital circuits and their construction and testing. Use of modern measurement equipment such as digital oscilloscopes and evaluation of the measurement results obtained in comparison with circuit simulations of analog electronics. Use and programming of modern digital electronics hardware (FPGAs) and evaluation of the results obtained.

Content
Introduction to analog and digital electronics:

- The "electronics chain" of detectors in experimental physics
- Fundamentals, linear networks, passive components, filters
- Elementary circuit analysis and simulation
- Operational amplifiers, Bipolar and field effect transistors
- Basic circuits with one and two transistors
- Number systems, circuit algebra, logic devices, flip-flops, memories
- Analog-to-digital converters
- Programmable electronics: CPLDs, FPGAs
- Packaging and interconnection technology
- Noise in detector systems

Workload
300 hours consisting of attendance time (75 hours), wrap-up of lecture and completion of exercises and lab (225 hours).

Recommendation
Interest in electronics

Literature
Literature will be mentioned in the lecture. A script will also be provided.
4.70 Module: Electronics for Physicists: Analog Electronics [M-PHYS-102179]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Grading scale**

Grade to a tenth

**Recurrence**

Each winter term

**Duration**

1 term

**Language**

English

**Level**

4

**Version**

1

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor) must not have been started.
2. The module M-PHYS-102182 - Electronics for Physicists: Digital Electronics must not have been started.
3. The module M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor) must not have been started.
4. The module M-PHYS-102184 - Electronics for Physicists must not have been started.
5. The module M-PHYS-102185 - Electronics for Physicists (Minor) must not have been started.

**Competence Goal**

Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics. Provide a basic understanding of analog electronics and its application in experimental physics. Understanding of analog circuits and their construction and testing. Use of modern measurement equipment such as digital oscilloscopes and evaluation of the measurement results obtained using, among other things, circuit simulation programs.

**Content**

Introduction to analog electronics:

- The “electronics chain” of detectors in experimental physics
- Fundamentals, linear networks, passive components, filters
- Elementary circuit analysis and simulation
- Operational amplifiers, Bipolar and field effect transistors
- Basic circuits with one and two transistors
- Packaging and interconnection technology
- Noise in detector systems

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and processing of the exercises and the internship (135 hours).

**Recommendation**

Interest in electronics

**Literature**

Literature will be mentioned in the lecture. A script will also be provided.
**Module: Electronics for Physicists: Analog Electronics (Minor) [M-PHYS-102180]**

**Responsible:**
- PD Dr. Klaus Rabbertz
- Prof. Dr. Frank Simon

**Organisation:**
- KIT Department of Physics

**Part of:**
- Minor in Physics: Experimental Particle Physics
- Minor in Physics: Experimental Astroparticle Physics

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**Competence Certificate**

The course credit is achieved through successful participation in the practical exercises. The details will be announced in the first lecture or at the first practical exercises.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102179 - Electronics for Physicists: Analog Electronics must not have been started.
2. The module M-PHYS-102182 - Electronics for Physicists: Digital Electronics must not have been started.
3. The module M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor) must not have been started.
4. The module M-PHYS-102184 - Electronics for Physicists must not have been started.
5. The module M-PHYS-102185 - Electronics for Physicists (Minor) must not have been started.

**Competence Goal**

Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics.

Provide a basic understanding of analog electronics and its application in experimental physics. Understanding of analog circuits and their construction and testing. Use of modern measurement equipment such as digital oscilloscopes and evaluation of the measurement results obtained using, among other things, circuit simulation programs.

**Content**

Introduction to analog electronics:

- The “electronics chain” of detectors in experimental physics
- Fundamentals, linear networks, passive components, filters
- Elementary circuit analysis and simulation
- Operational amplifiers, Bipolar and field effect transistors
- Basic circuits with one and two transistors
- Packaging and interconnection technology
- Noise in detector systems

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture and work on the exercises and the internship (135 hours).

**Recommendation**

Interest in electronics

**Literature**

Literature will be mentioned in the lecture. A script will also be provided.
Module: Electronics for Physicists: Digital Electronics [M-PHYS-102182]

**Responsible:**
PD Dr. Klaus Rabbertz
Prof. Dr. Frank Simon

**Organisation:**
KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

**Credits**
6

**Grading scale**
Grade to a tenth

**Recurrence**
Each winter term

**Duration**
1 term

**Language**
English

**Level**
4

**Version**
1

### Mandatory

| T-PHYS-104477 | Electronics for Physicists: Digital Electronics | 6 CR | Rabbertz, Simon |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor) must not have been started.
2. The module M-PHYS-102179 - Electronics for Physicists: Analog Electronics must not have been started.
3. The module M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor) must not have been started.
4. The module M-PHYS-102184 - Electronics for Physicists must not have been started.
5. The module M-PHYS-102185 - Electronics for Physicists (Minor) must not have been started.

**Competence Goal**

Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics.

Providing a basic understanding of digital electronics and its application in experimental physics. Understanding of digital circuits and their construction and testing. Use and programming of modern digital electronics hardware (FPGAs) and evaluation of the obtained results.

**Content**

Introduction to digital electronics:

- The "electronics chain" of detectors in experimental physics
- Number systems, circuit algebra, logic devices, flip-flops, memories
- Analog-to-digital converters
- Programmable electronics: CPLDs, FPGAs

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and processing of the exercises and the internship (135 hours).

**Recommendation**

Interest in electronics

**Literature**

Literature will be mentioned in the lecture. A script will also be provided.
4.73 Module: Electronics for Physicists: Digital Electronics (Minor) [M-PHYS-102183]

Responsible: PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

Organisation: KIT Department of Physics

Part of: Minor in Physics: Experimental Particle Physics  
Minor in Physics: Experimental Astroparticle Physics

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Mandatory

| T-PHYS-104478 | Electronics for Physicists: Digital Electronics (Minor) | 6 CR | Rabbertz, Simon |

Competence Certificate

The course credit is achieved through successful participation in the practical exercises. The details will be announced in the first lecture or at the first practical exercises.

Prerequisites

none

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-102182 - Electronics for Physicists: Digital Electronics must not have been started.
2. The module M-PHYS-102179 - Electronics for Physicists: Analog Electronics must not have been started.
3. The module M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor) must not have been started.
4. The module M-PHYS-102184 - Electronics for Physicists must not have been started.
5. The module M-PHYS-102185 - Electronics for Physicists (Minor) must not have been started.

Competence Goal

Deepening knowledge in technical aspects of experimental physics, with an emphasis on instrumentation for particle and astroparticle physics. Providing a basic understanding of digital electronics and its application in experimental physics. Understanding of digital circuits and their construction and testing. Use and programming of modern digital electronics hardware (FPGAs) and evaluation of the obtained results.

Content

Introduction to digital electronics:

• The "electronics chain" of detectors in experimental physics
• Number systems, circuit algebra, logic devices, flip-flops, memories
• Analog-to-digital converters
• Programmable electronics: CPLDs, FPGAs

Workload

180 hours consisting of attendance time (45 hours), wrap-up of the lecture and work on the exercises and the internship (135 hours).

Recommendation

Interest in electronics

Literature

Literature will be mentioned in the lecture. A script will also be provided.
### 4.74 Module: Experimental Biophysics II, with Seminar [M-PHYS-102165]

**Responsible:** Prof. Dr. Ulrich Nienhaus

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Required Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

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**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102166 - Experimental Biophysics II, with Seminar (Minor) must not have been started.
2. The module M-PHYS-102167 - Experimental Biophysics II, without Seminar must not have been started.
3. The module M-PHYS-102168 - Experimental Biophysics II, without Seminar (Minor) must not have been started.

**Competence Goal**

The students

- are able to describe the basic structure of biomatter and are familiar with its structural, dynamic and energetic properties.
- understand the physical principles of biomolecular spectroscopy and can appreciate the application of the various methods to the study of biomolecular processes.
- are familiar with the basic approaches to relaxation and fluctuation spectroscopy.
- understand the physical principles of interactions essential to molecular functional processes (chemical bonding, electron transfer, energy transfer) and the parameters that determine transition rates.
- acquire in-depth knowledge during the exercises by solving exercise problems. They present their results and thus further develop their abilities to share the acquired knowledge with the other students.
- independently acquire in-depth knowledge on a special topic of biophysics and give a presentation on this topic. They thus develop their skills in scientific presentation, which includes the selection of the material from a didactic point of view, the structuring of the lecture, the slide design, the actual presentation and answering questions from the audience.

**Content**

After a brief introduction to the structure, dynamics and energetics of biomolecules, light-optical spectroscopic methods (including optical absorption and fluorescence, infrared and Raman spectroscopy) are introduced, which can be used to observe biomolecular structures and their changes as a function of time. Light microscopy including super-resolution techniques are covered as well. The physical principles on which important biomolecular processes (ligand binding, energy and electron transfer in photosynthesis) are based are then discussed.

**Workload**

420 hours consisting of attendance time (120 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises as well as the seminar presentation (300 hours).

**Recommendation**

Fundamentals of quantum mechanics, thermodynamics, and solid state physics are assumed.
Literature

- G. U. Nienhaus: Skripten zur Vorlesung Biophysik I und II
- E. Sackmann & R. Merkel: Lehrbuch der Biophysik
- C. Cantor & P. Schimmel: Biophysical Chemistry
- I. N. Serdyuk, N. R. Zaccai & J. Zaccai: Methods in Molecular Biophysics
Module: Experimental Biophysics II, with Seminar (Minor) [M-PHYS-102166]

**Responsible:** Prof. Dr. Ulrich Nienhaus

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Nanophysics
Minor in Physics: Optics and Photonics

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**Mandatory**

| T-PHYS-102533 | Experimental Biophysics II, with Seminar (Minor) | 14 CR | Nienhaus |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102165 - Experimental Biophysics II, with Seminar must not have been started.
2. The module M-PHYS-102167 - Experimental Biophysics II, without Seminar must not have been started.
3. The module M-PHYS-102168 - Experimental Biophysics II, without Seminar (Minor) must not have been started.

**Competence Goal**
The students

- are able to describe the basic structure of biomatter and are familiar with its structural, dynamic and energetic properties.
- understand the physical principles of biomolecular spectroscopy and can appreciate the application of the various methods to the study of biomolecular processes.
- are familiar with the basic approaches to relaxation and fluctuation spectroscopy.
- understand the physical principles of interactions essential to molecular functional processes (chemical bonding, electron transfer, energy transfer) and the parameters that determine transition rates.
- acquire in-depth knowledge during the exercises by solving exercise problems. They present their results and thus further develop their abilities to share the acquired knowledge with the other students.
- independently acquire in-depth knowledge on a special topic of biophysics and give a presentation on this topic. They thus develop their skills in scientific presentation, which includes the selection of the material from a didactic point of view, the structuring of the lecture, the slide design, the actual presentation and answering questions from the audience.

**Content**

After a brief introduction to the structure, dynamics and energetics of biomolecules, light-optical spectroscopic methods (including optical absorption and fluorescence, infrared and Raman spectroscopy) are introduced, which can be used to observe biomolecular structures and their changes as a function of time. Light microscopy including super-resolution techniques are covered as well. The physical principles on which important biomolecular processes (ligand binding, energy and electron transfer in photosynthesis) are based are then discussed.

**Workload**

420 hours consisting of attendance time (120 hours), wrap-up of the lecture and preparation of the exercises as well as the seminar presentation (300 hours).

**Recommendation**

Fundamentals of quantum mechanics, thermodynamics, and solid state physics are assumed.
Literature

- G. U. Nienhaus: Skripten zur Vorlesung Biophysik I und II
- E. Sackmann & R. Merkel: Lehrbuch der Biophysik
- C. Cantor & P. Schimmel: Biophysical Chemistry
- I. N. Serdyuk, N. R. Zaccai & J. Zaccai: Methods in Molecular Biophysics
Module: Experimental Biophysics II, without Seminar [M-PHYS-102167]

**Responsible:** Prof. Dr. Ulrich Nienhaus

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Required Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

**Credits** 12

**Grading scale** Grade to a tenth

**Recurrence** Each summer term

**Duration** 1 term

**Language** German

**Level** 4

**Version** 1

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**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102165 - Experimental Biophysics II, with Seminar must not have been started.
2. The module M-PHYS-102166 - Experimental Biophysics II, with Seminar (Minor) must not have been started.
3. The module M-PHYS-102168 - Experimental Biophysics II, without Seminar (Minor) must not have been started.

**Competence Goal**

The students

- are able to describe the basic structure of biomatter and are familiar with its structural, dynamic and energetic properties.
- understand the physical principles of biomolecular spectroscopy and can appreciate the application of the various methods to the study of biomolecular processes.
- are familiar with the basic approaches to relaxation and fluctuation spectroscopy.
- understand the physical principles of interactions essential to molecular functional processes (chemical bonding, electron transfer, energy transfer) and the parameters that determine transition rates.
- acquire in-depth knowledge during the exercises by solving exercise problems. They present their results and thus further develop their ability to share the acquired knowledge with the other students.

**Content**

After a brief introduction to the structure, dynamics and energetics of biomolecules, light-optical spectroscopic methods (including optical absorption and fluorescence, infrared and Raman spectroscopy) are introduced, which can be used to observe biomolecular structures and their changes as a function of time. Light microscopy including super-resolution techniques are covered as well. The physical principles on which important biomolecular processes (ligand binding, energy and electron transfer in photosynthesis) are based are then discussed.

**Workload**

360 hours consisting of attendance time (90 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (270 hours).

**Recommendation**

Fundamentals of quantum mechanics, thermodynamics, and solid state physics are assumed.

**Literature**

- G. U. Nienhaus: Skripten zur Vorlesung Biophysik I und II
- E. Sackmann & R. Merkel: Lehrbuch der Biophysik
- C. Cantor & P. Schimmel: Biophysical Chemistry
- I. N. Serdyuk, N. R. Zaccai & J. Zaccai: Methods in Molecular Biophysics
### Module: Experimental Biophysics II, without Seminar (Minor) [M-PHYS-102168]

**Responsible:** Prof. Dr. Ulrich Nienhaus

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Nanophysics
- Minor in Physics: Optics and Photonics

**Credits:** 12

**Grading scale:** pass/fail

**Recurrence:** Each summer term

**Duration:** 1 term

**Language:** German

**Level:** 4

**Version:** 1

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**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102165 - Experimental Biophysics II, with Seminar must not have been started.
2. The module M-PHYS-102166 - Experimental Biophysics II, with Seminar (Minor) must not have been started.
3. The module M-PHYS-102167 - Experimental Biophysics II, without Seminar must not have been started.

**Competence Goal**

The students

- are able to describe the basic structure of biomatter and are familiar with its structural, dynamic and energetic properties.
- understand the physical principles of biomolecular spectroscopy and can appreciate the application of the various methods to the study of biomolecular processes.
- are familiar with the basic approaches to relaxation and fluctuation spectroscopy.
- understand the physical principles of interactions essential to molecular functional processes (chemical bonding, electron transfer, energy transfer) and the parameters that determine transition rates.
- acquire in-depth knowledge during the exercises by solving exercise problems. They present their results and thus further develop their ability to share the acquired knowledge with the other students.

**Content**

After a brief introduction to the structure, dynamics and energetics of biomolecules, light-optical spectroscopic methods (including optical absorption and fluorescence, infrared and Raman spectroscopy) are introduced, which can be used to observe biomolecular structures and their changes as a function of time. Light microscopy including super-resolution techniques are covered as well. The physical principles on which important biomolecular processes (ligand binding, energy and electron transfer in photosynthesis) are based are then discussed.

**Workload**

360 hours consisting of attendance time (90 hours), wrap-up of the lecture and preparation of the exercises (270 hours).

**Recommendation**

Fundamentals of quantum mechanics, thermodynamics, and solid state physics are assumed.

**Literature**

- G. U. Nienhaus: Skripten zur Vorlesung Biophysik I und II
- E. Sackmann & R. Merkel: Lehrbuch der Biophysik
- C. Cantor & P. Schimmel: Biophysical Chemistry
- I. N. Serdyuk, N. R. Zaccai & J. Zaccai: Methods in Molecular Biophysics
Module: Field Theories of Condensed Matter: Conformal Field Theory [M-PHYS-104548]

**Responsible:** PD Dr. Igor Gornyi  
PD Dr. Boris Narozhnyy

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)  
Second Major in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-109320 | Field Theories of Condensed Matter: Conformal Field Theory | 8 CR | Gornyi, Narozhnyy |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

None

**Competence Goal**

The students understand the theory of condensed matter and know the most important phenomena and concepts in the physics of low-dimensional quantum systems, as well as the corresponding field-theoretical approaches.

**Content**

Preliminary structure:

1. Introduction
2. Conformal transformations, conformal group in d dimensions, conformal algebra in 2 dimensions
3. Conformal theories in 2 dimensions, central charge, Virasoro algebra
4. Scaling approach to critical phenomena, Ising model, Potts model
5. Bosonization in 1+1 dimensions, Gaussian model, XXZ model
6. Non-Abelian bosonization, Sugawara construction

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation (180 hours)

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and statistical physics is assumed. It is recommended to take this course after the course Theorie der Kondensierten Materie I.

**Literature**

E. Brezin and J. Zinn-Justin (Editors), Fields, Strings, and critical Phenomena (Les Houches 1988)  
P. Di Francesco, P. Mathieu, and D. Senechal, Conformal Field Theory.  
T. Giamarchi, Quantum Physics in One Dimension  
A.O. Gogolin, A.A. Nersesyan, A.M. Tsvelik, Bosonization and Strongly Correlated Systems
Module: Flavour Physics in the Standard Model and beyond [M-PHYS-105064]

Responsible: Dr. Monika Blanke
Prof. Dr. Ulrich Nierste

Organisation: KIT Department of Physics

Part of: Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
Second Major in Physics: Theoretical Particle Physics

Credits 4
Grading scale Grade to a tenth
Recurrence Irregular
Duration 1 term
Language English
Level 4
Version 1

Mandatory
T-PHYS-110281 Flavour Physics in the Standard Model and beyond 4 CR Blanke, Nierste

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Competence Goal
Students will learn and deepen the methodology of Theoretical Flavour Physics. They have an understanding of the phenomenology of the flavor sector in and beyond the Standard Model.

Content
- Flavour and CP violation in the Standard Model
- Determination of CKM elements
- Phenomenology of flavour and CP violating processes
- Flavour physics beyond the Standard Model: Minimal Flavour Violation
- New sources of flavour and CP violation
- Selected "hot topics" in rare meson decays

Workload
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours).

Recommendation
Basic knowledge of the Standard Model of particle physics, in particular of the strong and weak interaction as well as the Yukawa sector, e.g. from the lecture "Introduction to Theoretical Particle Physics". It is recommended to attend the lecture on experimental flavor physics in parallel.

Literature
Will be given in the lecture
### Module: Full-Waveform Inversion (Ungraded) [M-PHYS-104522]

**Responsible:** Prof. Dr. Thomas Bohlen  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Geophysics

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**Mandatory**

| T-PHYS-109272 | Full-Waveform Inversion | 6 CR | Bohlen, Hertweck |

**Competence Certificate**
Final pass based on successful participation of the exercises.

**Prerequisites**
None

**Competence Goal**
The students know the fundamentals about full-waveform inversion from theory to practical implementation. They understand the basic concept of full-waveform inversion and grid-based finite-difference schemes to solve the wave equation. They understand important practical aspects such as numerical effects and critical performance issues. Students are able to implement a basic full-waveform inversion algorithm and apply it to simple data sets. They can analyze important factors influencing the success of full-waveform inversion and assess the quality of inversion results.

**Content**
- Introduction to full-waveform inversion (FWI)  
- Solution of the wave equation with the finite-difference method  
- Practical issues and numerical effects  
- Adjoint-state method  
- Adaption of the adjoint-state method for FWI  
- FWI of shallow seismic wavefields

**Module grade calculation**
The coursework is not graded.

**Workload**
180 h hours composed of contact time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**
Knowledge of differential calculus is essential. Experience with Matlab and general computer skills are beneficial.

**Learning type**
4060181 Seismic Full Waveform Inversion (V2)  
4060182 Exercises to Seismic Full Waveform Inversion (Ü1)

**Literature**
- Andreas Fichtner, "Full Seismic Waveform Modelling and Inversion", 2011, Springer.
Module: General Relativity [M-PHYS-102319]

**Responsible:** Prof. Dr. Frans Klinkhamer  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
- Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-102395 | General Relativity | 10 CR | Klinkhamer |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102320 - General Relativity (Minor) must not have been started.  
2. The module M-PHYS-106532 - Introduction to General Relativity must not have been started.  
3. The module M-PHYS-106533 - Introduction to General Relativity (Minor) must not have been started.

**Competence Goal**  
The students broaden their intellectual horizon by learning and thinking about one of the great achievements of humanity, the discovery of the dynamic nature of spacetime. Students know and understand the basic ideas of Special Relativity and are familiar with the main concepts and techniques of General Relativity. They know different cosmological models. Participants of the course can apply the concepts and techniques they have learned to solve selected practical problems.

**Content**  
This lecture consists of three parts.  
The first part reviews the basic ideas of Special Relativity.  
The second part introduces the main concepts and techniques of General Relativity.  
The third part discusses cosmological models.

**Workload**  
Approximately 300 hours, consisting of 75 hours for direct presence and further time for literature study, preparation of exercise problems or tasks, and possibly preparation for the final oral exam.

**Recommendation**  
A basic understanding of classical mechanics, classical electrodynamics, and quantum mechanics.

**Literature**

4.82 Module: General Relativity (Minor) [M-PHYS-102320]

**Responsible:** Prof. Dr. Frans Klinkhamer

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Experimental Astroparticle Physics
- Minor in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-102446 | General Relativity (Minor) | 10 CR | Klinkhamer |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102319 - General Relativity must not have been started.
2. The module M-PHYS-106532 - Introduction to General Relativity must not have been started.
3. The module M-PHYS-106533 - Introduction to General Relativity (Minor) must not have been started.

**Competence Goal**
The students broaden their intellectual horizon by learning and thinking about one of the great achievements of humanity, the discovery of the dynamic nature of spacetime. Students know and understand the basic ideas of Special Relativity and are familiar with the main concepts and techniques of General Relativity. They know different cosmological models. Participants of the course can apply the concepts and techniques they have learned to solve selected practical problems.

**Content**
This lecture consists of three parts.
The first part reviews the basic ideas of Special Relativity.
The second part introduces the main concepts and techniques of General Relativity.
The third part discusses cosmological models.

**Workload**
Approximately 300 hours, consisting of 75 hours for direct presence and further time for literature study, preparation of exercise problems or tasks.

**Recommendation**
A basic understanding of classical mechanics, classical electrodynamics, and quantum mechanics.

**Literature**

4.83 Module: General Relativity II [M-PHYS-103333]

**Responsible:** Prof. Dr. Frans Klinkhamer  
**Organisation:** KIT Department of Physics  
**Part of:** Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-106678 | General Relativity II | 10 CR | Klinkhamer |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-103334 - General Relativity II (Minor) must not have been started.

**Competence Goal**

The students are familiar with the concepts of modern cosmology and understand how various realms of physics come into play for the description of the universe and its history. During the course of the lecture they have deepened their understanding of previous physics courses and can apply this knowledge to problems that require an interdisciplinary approach.

**Content**

This lecture course is a follow-up of ART I (GR I) and is divided into three parts:

- The first part deals with the physics of the early universe.
- The second part discusses spacetime structure from the viewpoint of global discrete symmetries, topology, and spacetime defects.
- The third part introduces basic ideas of string theory as a particular approach to quantum gravity.

**Workload**

Approximately 300 hours, consisting of 75 hours for direct presence and further time for literature study, preparation of exercise problems or tasks, and possibly preparation for the final oral exam.

**Recommendation**

GR I (ART I)

**Literature**

4.84 Module: General Relativity II (Minor) [M-PHYS-103334]

**Responsible:** Prof. Dr. Frans Klinkhamer

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-106679 | General Relativity II (Minor) | 10 CR | Klinkhamer |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-103333 - General Relativity II must not have been started.

**Competence Goal**
The students are familiar with the concepts of modern cosmology and understand how various realms of physics come into play for the description of the universe and its history. During the course of the lecture they have deepened their understanding of previous physics courses and can apply this knowledge to problems that require an interdisciplinary approach.

**Content**
This lecture course is a follow-up of ART I (GR I) and is divided into three parts:
The first part deals with the physics of the early universe.
The second part discusses spacetime structure from the viewpoint of global discrete symmetries, topology, and spacetime defects.
The third part introduces basic ideas of string theory as a particular approach to quantum gravity.

**Workload**
Approximately 300 hours, consisting of 75 hours for direct presence and further time for literature study, preparation of exercise problems or tasks.

**Recommendation**
GR I (ART I)

**Literature**
4.85 Module: Geological Hazards and Risk [M-PHYS-101833]

**Responsible:** Dr. Andreas Schäfer  
**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Geophysics

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**Mandatory**

| T-PHYS-103525 | Geological Hazards and Risk | 8 CR | Schäfer |

**Competence Certificate**  
Active and regular attendance of lecture and practicals. Project work (graded).

**Prerequisites**  
none

**Competence Goal**  
The students understand basic concepts of hazard and risk. They can explain in detail different aspects of earthquake hazard, volcanic hazard as well as other geological hazards, can compare and evaluate those hazards. They have fundamental knowledge of risk reduction and risk management. They know methods of risk modelling and are able to apply them.

**Content**

- Earthquake Hazards
  - Short introduction to seismology and seismometry (occurrence of tectonic earthquakes, types of seismic waves, magnitude, intensity, source physics)
  - Induced seismicity
  - Engineering seismology, Recurrence intervals, Gutenberg-Richter, PGA, PGV, spectral acceleration, hazard maps
  - Earthquake statistics
  - Liquefaction
- Tsunami Hazards
- Landslide Hazards
- Hazards from Sinkholes
- Volcanic Hazards
  - Short introduction to physical volcanology
  - Types of volcanic hazards
- The Concept of Risk, Damage and Loss
- Data Analysis and the use of GIS in Risk analysis
- Risk Modelling - Scenario Analysis
- Risk Reduction and Risk Management
- Analysis Feedback and Prospects in the Risk Modelling Industry

**Module grade calculation**  
Project work will be graded.

**Workload**

- 60 h: active attendance during lectures and exercises
- 90 h: review, preparation and weekly assignments
- 90 h: project work
**Learning type**
4060121 Geological Hazards and Risk (V2)
4060122 Übungen zu Geological Hazards and Risk (Ü2)

**Literature**
Literature will be provided by the lecturer.
M 4.86 Module: In-Situ: Tectonics and Seismic Hazard in the Mediterranean Region [M-PHYS-106322]

**Responsible:** Prof. Dr. Andreas Rietbrock  
**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Geophysics

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**Competence Certificate**  
Students solve exercise sheets, prepare and give a presentation and write a final report.

**Competence Goal**  
Students understand the geodynamic and tectonic situation in the Mediterranean and especially in seismic active regions. They gain profound knowledge about seismic hazard, can explain the concept of seismic hazard assessment, and can apply it. They can name different monitoring methods, explain them and apply them under guidance.

**Content**  
- Geodynamics of the Mediterranean  
- Tectonics in Greece, Italy and the Balkans  
- Seismic hazard, with focus on the Mediterranean  
- Seismic monitoring  
- Field work

**Module grade calculation**  
The final mark is computed from all submissions.

**Workload**  
180 h in total, composed of:
1. Lecture at KIT before in-situ part: 15 h  
2. Data analysis at KIT: 5 h  
3. Preparation of presentation and handout: 30 h  
4. In-situ lecture: 80 h  
5. Wrap-up of lectures, solving exercise sheets and preparation of report: 50 h

**Learning type**  
4060351 (In-Situ: Tectonics and Seismic Hazard in the Mediterranean Region),  
4060352 (Exercises on In-Situ: Tectonics and Seismic Hazard in the Mediterranean Region).

**Literature**  
Will be announced during the lecture.
4.87 Module: Interdisciplinary Qualifications [M-PHYS-101394]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** Interdisciplinary Qualifications

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**Electives Interdisciplinary Qualifications (Election: at least 4 credits)**

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<td>T-PHYS-111565</td>
<td>Selfassignment-MScPhysics-ungraded</td>
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<td>Studiendekan Physik</td>
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**Prerequisites**

none

**Annotation**

Interdisciplinary qualifications (IQ) completed at the House-of-Competence (HoC), at the Zentrum für Angewandte Kulturwissenschaften (ZAK) or at the Sprachenzentrum (SpZ) can be assigned in self-service. First, select a partial accomplishment named "self-assignment" in your study schedule and second, assign an IQ-achievement via the tab "IQ achievements".
4.88 Module: Introduction to Cosmology [M-PHYS-102175]

**Responsible:** Prof. Dr. Guido Drexlin

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Astroparticle Physics (Required Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Required Experimental Astroparticle Physics)

**Credits:** 6

**Grading scale:** Grade to a tenth

**Recurrence:** Each winter term

**Duration:** 1 term

**Language:** English

**Level:** 4

**Version:** 1

**Mandatory**

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<td>6 CR</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102176 - Introduction to Cosmology (Minor)** must not have been started.

**Competence Goal**

Students will be introduced to the basic concepts of cosmology. The lecture will provide both the theoretical concepts and an overview of modern experimental methods and observational techniques. The students will be enabled to understand the concepts by means of concrete case studies from modern cosmology and will be enabled to apply the learned methods in the context of later independent research.

**Methodological Competency Acquisition:**

- Understanding of the fundamentals of cosmology
- Recognition of methodological cross-connections to elementary particle physics and astroparticle physics.
- Acquisition of the ability to work independently on current research topics as preparation for the master thesis.

**Content**

The lecture offers an introduction to modern cosmology, which has taken an enormous upswing in recent years due to the use of state-of-the-art technologies (Planck satellite, galaxy surveys such as 2dF and SDSS) and accompanying computationally intensive simulations (Millennium). The large number of observations has led to the establishment of a so-called concordance model of cosmology, in which the contributions of dark energy and dark matter dominate the evolution of large-scale structures in the universe.

Starting from a description of the early universe with the supporting pillars of the Big Bang theory (Hubble expansion, nucleosynthesis, cosmic background radiation) and the phase transitions and symmetry breaking that occur in the process, the formation and evolution of large-scale structures in the universe up to today's “dark universe” is discussed (comparison of “top-down” with “bottom-up” models). Special attention is given to a detailed presentation of the most modern experimental techniques and methods of analysis, which have found their way into wide areas of physics.

The lecture thus provides a coherent picture of modern cosmology and discusses fundamental issues also in neighboring disciplines such as particle physics and astrophysics and can therefore be complemented with other lectures in the field of Experimental Astroparticle Physics and Experimental Particle Physics.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Basic knowledge from lecture "Nuclei and Particles"

**Literature**

Will be mentioned in the lecture.
### 4.89 Module: Introduction to Cosmology (Minor) [M-PHYS-102176]

**Responsible:** Prof. Dr. Guido Drexlin  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Experimental Astroparticle Physics

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#### Mandatory

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<td>Introduction to Cosmology (Minor)</td>
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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102175 - Introduction to Cosmology must not have been started.

**Competence Goal**
Students will be introduced to the basic concepts of cosmology. The lecture will provide both the theoretical concepts and an overview of modern experimental methods and observational techniques. The students will be enabled to understand the concepts by means of concrete case studies from modern cosmology and will be enabled to apply the learned methods in the context of later independent research.

**Methodological Competency Acquisition:**

- Understanding of the fundamentals of cosmology
- Recognition of methodological cross-connections to elementary particle physics and astroparticle physics.
- Acquisition of the ability to work independently on current research topics as preparation for the master thesis.

**Content**
The lecture offers an introduction to modern cosmology, which has taken an enormous upswing in recent years due to the use of state-of-the-art technologies (Planck satellite, galaxy surveys such as 2dF and SDSS) and accompanying computationally intensive simulations (Millennium). The large number of observations has led to the establishment of a so-called concordance model of cosmology, in which the contributions of dark energy and dark matter dominate the evolution of large-scale structures in the universe.

Starting from a description of the early universe with the supporting pillars of the Big Bang theory (Hubble expansion, nucleosynthesis, cosmic background radiation) and the phase transitions and symmetry breaking that occur in the process, the formation and evolution of large-scale structures in the universe up to today's "dark universe" is discussed (comparison of "top-down" with "bottom-up" models). Special attention is given to a detailed presentation of the most modern experimental techniques and methods of analysis, which have found their way into wide areas of physics.

The lecture thus provides a coherent picture of modern cosmology and discusses fundamental issues also in neighboring disciplines such as particle physics and astrophysics and can therefore be complemented with other lectures in the field of Experimental Astroparticle Physics and Experimental Particle Physics.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**
Basic knowledge from lecture "Nuclei and Particles"

**Literature**
Will be mentioned in the lecture.
Module: Introduction to Flavor Physics, Fundamentals [M-PHYS-102987]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
- Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-105963 | Introduction to Flavor Physics, Fundamentals | 10 CR | Nierste |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102986 - Introduction to Flavor Physics, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-103188 - Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-103189 - Introduction to Flavor Physics, Fundamentals (Minor) must not have been started.

**Competence Goal**

Students will learn the methodology of Theoretical Flavour Physics, be able to solve complex mathematical problems such as calculating the decay amplitudes of mesons, and understand the phenomenology of the Yukawa sector.

**Content**


**Workload**

300 h consisting of attendance time (75 h), wrap-up of the lecture incl. exam preparation and working on the exercises (225 h)

**Recommendation**

It is useful to have prior knowledge about quantized fields and the standard model of particle physics, e.g. from the lecture "Introduction to Theoretical Particle Physics" (4026021). For students interested in theory it is useful to attend the lecture "Theoretical Particle Physics I" in parallel.

**Literature**

To be stated in the lecture.
Module: Introduction to Flavor Physics, Fundamentals (Minor) [M-PHYS-103189]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102986 - Introduction to Flavor Physics, Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-103188 - Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-102987 - Introduction to Flavor Physics, Fundamentals must not have been started.

**Competence Goal**
Students will learn the methodology of Theoretical Flavour Physics, be able to solve complex mathematical problems such as calculating the decay amplitudes of mesons, and understand the phenomenology of the Yukawa sector.

**Content**

**Workload**
300 h consisting of attendance time (75 h), wrap-up of the lecture and work on the exercises (225 h)

**Recommendation**
It is useful to have prior knowledge about quantized fields and the standard model of particle physics, e.g. from the lecture "Introduction to Theoretical Particle Physics" (4026021). For students interested in theory it is useful to attend the lecture "Theoretical Particle Physics I" in parallel.

**Literature**
To be stated in the lecture.
Module: Introduction to Flavor Physics, Fundamentals and Advanced Topics [M-PHYS-102986]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102987 - Introduction to Flavor Physics, Fundamentals must not have been started.
2. The module M-PHYS-103188 - Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor) must not have been started.
3. The module M-PHYS-103189 - Introduction to Flavor Physics, Fundamentals (Minor) must not have been started.

**Competence Goal**

Students will learn the methodology of Theoretical Flavour Physics, be able to solve complex mathematical problems such as calculating the decay amplitudes of mesons, and understand the phenomenology of the Yukawa sector. In addition, participants will have an understanding of CP asymmetries and decay rates of rare decays and their sensitivity to physics beyond the Standard Model.

**Content**


**Workload**

360 h consisting of attendance time (90 h), wrap-up of the lecture incl. exam preparation and working on the exercises (270 h)

**Recommendation**

It is useful to have prior knowledge about quantized fields and the standard model of particle physics, e.g. from the lecture "Introduction to Theoretical Particle Physics" (4026021). For students interested in theory it is useful to attend the lecture "Theoretical Particle Physics I" in parallel.

**Literature**

To be stated in the lecture.
**Module: Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor) [M-PHYS-103188]**

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102987 - Introduction to Flavor Physics, Fundamentals must not have been started.
2. The module M-PHYS-102986 - Introduction to Flavor Physics, Fundamentals and Advanced Topics must not have been started.
3. The module M-PHYS-103189 - Introduction to Flavor Physics, Fundamentals (Minor) must not have been started.

**Competence Goal**
Students will learn the methodology of Theoretical Flavour Physics, be able to solve complex mathematical problems such as calculating the decay amplitudes of mesons, and understand the phenomenology of the Yukawa sector. In addition, participants will have an understanding of CP asymmetries and decay rates of rare decays and their sensitivity to physics beyond the Standard Model.

**Content**

**Workload**
360 h consisting of attendance time (90 h), wrap-up of the lecture incl. exam preparation and working on the exercises (270 h)

**Recommendation**
It is useful to have prior knowledge about quantized fields and the standard model of particle physics, e.g. from the lecture "Introduction to Theoretical Particle Physics" (4026021). For students interested in theory it is useful to attend the lecture "Theoretical Particle Physics I" in parallel.

**Literature**
To be stated in the lecture.
Module: Introduction to General Relativity [M-PHYS-106532]

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102319 - General Relativity must not have been started.
2. The module M-PHYS-102320 - General Relativity (Minor) must not have been started.
3. The module M-PHYS-106533 - Introduction to General Relativity (Minor) must not have been started.

**Competence Goal**

Students know and understand the basic ideas of Special Relativity and are familiar with the main concepts and techniques of General Relativity. Students know about black holes, gravitational waves and simple cosmological models. Participants of the course can apply the concepts and techniques they have learned to solve selected problems in General Relativity.

**Content**

This lecture gives an introduction to General Relativity, the theory of space time and gravity. After a brief review of special relativity, the necessary tools to describe curved space time are introduced, as well as concepts such as the equivalence principle and geodesic motion. The Einstein equations are discussed, which relate the geometry of space time to the matter and energy content of it. In the second part of the lecture some important application of the General Relativity are discussed, including black holes, gravitational waves and the basics of cosmology.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

**Recommendation**

Basic knowledge on Special Relativity

**Literature**

- S. Carrol, Spacetime and Geometry - An Introduction to General Relativity, Cambridge Univ. Press 2019;
- S. Weinberg, Gravitation and Cosmology, Wiley, 1972;

more literature will be provided during the lecture.
Module: Introduction to General Relativity (Minor) [M-PHYS-106533]

Responsible: Prof. Dr. Thomas Schwetz-Mangold
Organisation: KIT Department of Physics
Part of: Minor in Physics: Experimental Astroparticle Physics
Minor in Physics: Theoretical Particle Physics

Credits: 8
Grading scale: pass/fail
Recurrence: Each winter term
Duration: 1 term
Language: English
Level: 4
Version: 1

Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-106532 - Introduction to General Relativity must not have been started.
2. The module M-PHYS-102319 - General Relativity must not have been started.
3. The module M-PHYS-102320 - General Relativity (Minor) must not have been started.

Competence Goal
Students know and understand the basic ideas of Special Relativity and are familiar with the main concepts and techniques of General Relativity. Students know about black holes, gravitational waves and simple cosmological models. Participants of the course can apply the concepts and techniques they have learned to solve selected problems in General Relativity.

Content
This lecture gives an introduction to General Relativity, the theory of space time and gravity. After a brief review of special relativity, the necessary tools to describe curved space time are introduced, as well as concepts such as the equivalence principle and geodesic motion. The Einstein equations are discussed, which relate the geometry of space time to the matter and energy content of it. In the second part of the lecture some important application of the General Relativity are discussed, including black holes, gravitational waves and the basics of cosmology.

Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

Recommendation
Basic knowledge on Special Relativity

Literature

- S. Carrol, Spacetime and Geometry - An Introduction to General Relativity, Cambridge Univ. Press 2019;
- S. Weinberg, Gravitation and Cosmology, Wiley, 1972;

More literature will be provided during the lecture.
M 4.96 Module: Introduction to Neutron Scattering [M-PHYS-106323]

Responsible: PD Dr. Frank Weber
Organisation: KIT Department of Physics
Part of: Major in Physics: Condensed Matter (Elective Condensed Matter)
Second Major in Physics: Condensed Matter (Elective Condensed Matter)

Credits 6
Grading scale Grade to a tenth
Recurrence Irregular
Duration 1 term
Language English
Level 4
Version 1

Mandatory
T-PHYS-112831 Introduction to Neutron Scattering 6 CR Weber

Competence Certificate
Zur Verwendung als Schwerpunktfach/Ergänzungsfach:
Mündliche Prüfung. Im Rahmen des Schwerpunktfachs des MSc Physik wird das Modul zusammen mit weiteren belegten Modulen geprüft. Die Dauer der mündlichen Prüfung beträgt insgesamt ca. 60 Minuten.

Competence Goal
The students understand the theoretical and technical basic principles of neutron scattering experiments. For a specific scientific question, the students are able to evaluate various neutron scattering techniques and select the best-suited one. Student are able to critically read and assess scientific publications based on neutron scattering techniques.

Content
This lecture familiarizes the students with the basic principles of neutron scattering, the theoretical description and experimental realization of neutron scattering experiments. We will discuss methods for structure determination and imaging based on nuclear and magnetic scattering mechanisms. Applications to investigate lattice and magnetic degrees of freedom discussed along with a short introduction to second quantization formalism and linear response theory. An overview and short comparison of complementary scattering methods (x-ray, electron) is given. The lecture will be illustrated with examples from current work on quantum materials.

• Basics of the neutron–matter interaction
• Concepts for the theoretical description of neutron scattering
• Production and detection of neutrons
• Structure determination with neutrons
• Inelastic neutron scattering – neutron spectroscopy
• Introduction: 2nd quantization, linear response
• Complementary scattering techniques

Workload
180 hours, composed of attendance time (45 hours), wrap-up of the lecture, working on the exercises and exam preparation (135 hours).

Recommendation
Basic knowledge of condensed matter physics, quantum mechanics, as well as thermodynamics and statistical physics are expected.

Literature
• Experimental Neutron Scattering, Willis & Carlile, Oxford
• Introduction to the theory of thermal neutron scattering, Squires, Dover
• Neutron scattering in condensed matter physics, Furrer & Strässle, World Scientific
• Neutron and synchrotron spectroscopy, ed.:Hippert et al., Springer
• Solid-State Spectroscopy, Kuzman, Springer
• Festkörperphysik, Gross und Marx, Oldenburg
4.97 Module: Introduction to Neutron Scattering (Minor) [M-PHYS-106324]

**Responsible:** PD Dr. Frank Weber  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Condensed Matter

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**Mandatory**

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<td>6 CR</td>
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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Competence Goal**
The students understand the theoretical and technical basic principles of neutron scattering experiments. For a specific scientific question, the students are able to evaluate various neutron scattering techniques and select the best-suited one. Student are able to critically read and assess scientific publications based on neutron scattering techniques.

**Content**
This lecture familiarizes the students with the basic principles of neutron scattering, the theoretical description and experimental realization of neutron scattering experiments. We will discuss methods for structure determination and imaging based on nuclear and magnetic scattering mechanisms. Applications to investigate lattice and magnetic degrees of freedom discussed along with a short introduction to second quantization formalism and linear response theory. An overview and short comparison of complementary scattering methods (x-ray, electron) is given. The lecture will be illustrated with examples from current work on quantum materials.

- Basics of the neutron-matter interaction  
- Concepts for the theoretical description of neutron scattering  
- Production and detection of neutrons  
- Structure determination with neutrons  
- Inelastic neutron scattering – neutron spectroscopy  
- Introduction: 2nd quantization, linear response  
- Complementary scattering techniques

**Workload**
180 hours, composed of attendance time (45 hours), wrap-up of the lecture and work on the exercises (135 hours).

**Recommendation**
Basic knowledge of condensed matter physics, quantum mechanics, as well as thermodynamics and statistical physics are expected.

**Literature**

- Experimental Neutron Scattering, Willis & Carlile, Oxford  
- Introduction to the theory of thermal neutron scattering, Squires, Dover  
- Neutron scattering in condensed matter physics, Furrer & Strässle, World Scientific  
- Neutron and synchrotron spectroscopy, ed.:Hippert et al., Springer  
- Solid-State Spectroscopy, Kuzmani, Springer  
- Festkörperphysik, Gross und Marx, Oldenburg
Module: Introduction to Scientific Methods [M-PHYS-101397]

**Responsible:** Studiendekan Physik  
**Organisation:** KIT Department of Physics  
**Part of:** Introduction to Scientific Methods

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**Mandatory**

| T-PHYS-102480 | Introduction to Scientific Methods | 15 CR | Studiendekan Physik |

**Competence Certificate**

Study achievement, ungraded.

**Prerequisites**
The following subjects of the course of study have to be passed:

- Major in Physics  
- Second Major in Physics  
- Minor in Physics  
- Non-Physics Elective  
- Advanced Physics Laboratory Course

**Competence Goal**

Students learn basic working methods that are necessary for successful scientific research. The working methods themselves are independent of the respective field of specialization, but are practiced and learned on the basis of a concrete task (topic of the master's thesis).

**Workload**

approx. 450 hours
# 4.99 Module: Introduction to Theoretical Cosmology [M-PHYS-104855]

## Responsible
TT-Prof. Dr. Felix Kahlhöfer  
Prof. Dr. Thomas Schwetz-Mangold

## Organisation
KIT Department of Physics

## Part of
- **Major in Physics: Theoretical Particle Physics** (Elective Theoretical Particle Physics)
- **Second Major in Physics: Theoretical Particle Physics**

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<td>4</td>
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## Prerequisites
none

## Modeled Conditions
The following conditions have to be fulfilled:

1. The module **M-PHYS-104856 - Introduction to Theoretical Cosmology (Minor)** must not have been started.

## Competence Goal
Students learn different aspects of the Big Bang theory. They understand the basic physical concepts and learn relevant methods of theoretical physics applied in cosmology.

## Content
The lecture gives an introduction in the standard model of cosmology, the so-called LCDM model. The fundamental physics principles of the model are discussed. Starting from fundamental theories such as general relativity, particle physics, thermodynamics and statistical physics, we derive the properties and predictions of the LCDM model. We consider the expansion of the Universe, dark matter, dark energy, cosmic structure formation, cosmic microwave background radiation, and the theory of Inflation.

## Workload
240 h consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and working on the exercises (180 h)

## Recommendation
Basic knowledge of General Relativity is recommended, but all required concepts will be introduced. Basic knowledge of particle physics is helpful.

## Literature
- S. Dodelson, *Modern Cosmology*;  
- S. Weinberg, *Cosmology*;  
- V. Mukhanov, *Physical Foundations of Cosmology*;

Additional literature will be announced in the lecture.
Module: Introduction to Theoretical Cosmology (Minor) [M-PHYS-104856]

**Responsible:** TT-Prof. Dr. Felix Kahlhöfer
Prof. Dr. Thomas Schwetz-Mangold

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

**Credits** 8
**Grading scale** pass/fail
**Recurrence** Irregular
**Duration** 1 term
**Language** German
**Level** 4
**Version** 1

**Mandatory**

| T-PHYS-109888 | Introduction to Theoretical Cosmology (Minor) | 8 CR Kahlhöfer, Schwetz-Mangold |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104855 - Introduction to Theoretical Cosmology must not have been started.

**Competence Goal**
Students learn different aspects of the Big Bang theory. They understand the basic physical concepts and learn relevant methods of theoretical physics applied in cosmology.

**Content**
The lecture gives an introduction in the standard model of cosmology, the so-called LCDM model. The fundamental physics principles of the model are discussed. Starting from fundamental theories such as general relativity, particle physics, thermodynamics and statistical physics, we derive the properties and predictions of the LCDM model. We consider the expansion of the Universe, dark matter, dark energy, cosmic structure formation, cosmic microwave background radiation, and the theory of inflation.

**Workload**
240 h consisting of attendance time (60 h), wrap-up of the lecture and working on the exercises (180 h)

**Recommendation**
Basic knowledge of General Relativity is recommended, but all required concepts will be introduced. Basic knowledge of particle physics is helpful.

**Literature**
- S. Dodelson, Modern Cosmology;
- S. Weinberg, Cosmology;
- V. Mukhanov, Physical Foundations of Cosmology;

Additional literature will be announced in the lecture.
**4.101 Module: Introduction to Theoretical Particle Physics, with ext. Exercises [M-PHYS-102221]**

**Responsible:**
PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-104536 | Introduction to Theoretical Particle Physics, with ext. Exercises | 10 CR | Gieseke, Heinrich, Melnikov, Mühleitner, Steinhauser |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102424 - Introduction to Theoretical Particle Physics, with ext. Exercises (Minor)** must not have been started.
2. The module **M-PHYS-102425 - Introduction to Theoretical Particle Physics, without ext. Exercises** must not have been started.
3. The module **M-PHYS-102426 - Introduction to Theoretical Particle Physics, without ext. Exercises (Minor)** must not have been started.

**Competence Goal**

The students obtain basic knowledge about the topics, concepts and tools used in theoretical particle physics. They obtain an overview of the typical questions and problems. The students deepen their knowledge in the exercises tailored to the lecture.

**Content**

Lagrange densities, symmetries and conservation laws, Feynman rules, cross sections, elementary processes in QED, spontaneous symmetry breaking, Higgs mechanism, Standard Model of particle physics, decay rates, Higgs boson phenomenology

**Workload**

300 hours consisting of attendance time (75 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (225 hours)

**Recommendation**

Basic knowledge in quantum mechanics I and II

**Literature**

Will be provided in the first lecture.
Module: Introduction to Theoretical Particle Physics, with ext. Exercises (Minor) [M-PHYS-102424]

**Responsible:**
PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:**
KIT Department of Physics

**Part of:**
Minor in Physics: Theoretical Particle Physics

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<td>German/English</td>
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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102221 - Introduction to Theoretical Particle Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-102425 - Introduction to Theoretical Particle Physics, without ext. Exercises must not have been started.
3. The module M-PHYS-102426 - Introduction to Theoretical Particle Physics, without ext. Exercises (Minor) must not have been started.

**Competence Goal**
The students obtain basic knowledge about the topics, concepts and tools used in theoretical particle physics. They obtain an overview of the typical questions and problems. The students deepen their knowledge in the exercises tailored to the lecture.

**Content**
Lagrange densities, symmetries and conservation laws, Feynman rules, cross sections, elementary processes in QED, spontaneous symmetry breaking, Higgs mechanism, Standard Model of particle physics, decay rates, Higgs boson phenomenology

**Workload**
300 hours consisting of attendance time (75 hours), wrap-up of the lecture and preparation of the exercises (225 hours).

**Recommendation**
Basic knowledge in quantum mechanics I and II

**Literature**
Will be provided in the first lecture.
Module: Introduction to Theoretical Particle Physics, without ext. Exercises [M-PHYS-102425]

**Responsible:**
PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Credits: 8**

**Grading scale:** Grade to a tenth

**Recurrence:** Each winter term

**Duration:** 1 term

**Language:** German/English

**Level:** 4

**Version:** 1

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**Mandatory**

| T-PHYS-104792 | Introduction to Theoretical Particle Physics, without ext. Exercises | 8 CR | Gieseke, Heinrich, Melnikov, Mühlleitner, Steinhauser |

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

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**Prerequisites**

none

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**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102221 - Introduction to Theoretical Particle Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-102424 - Introduction to Theoretical Particle Physics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102426 - Introduction to Theoretical Particle Physics, without ext. Exercises (Minor) must not have been started.

---

**Competence Goal**

The students obtain basic knowledge about the topics, concepts and tools used in theoretical particle physics. They obtain an overview of the typical questions and problems.

---

**Content**

Lagrange densities, symmetries and conservation laws, Feynman rules, cross sections, elementary processes in QED, spontaneous symmetry breaking, Higgs mechanism, Standard Model of particle physics, decay rates, Higgs boson phenomenology

---

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

---

**Recommendation**

Basic knowledge in quantum mechanics I and II

---

**Literature**

Will be provided in the first lecture.
Module: Introduction to Theoretical Particle Physics, without ext. Exercises (Minor) [M-PHYS-102426]

**Responsible:** PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102221 - Introduction to Theoretical Particle Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-102424 - Introduction to Theoretical Particle Physics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102425 - Introduction to Theoretical Particle Physics, without ext. Exercises must not have been started.

**Competence Goal**
The students obtain basic knowledge about the topics, concepts and tools used in theoretical particle physics. They obtain an overview of the typical questions and problems.

**Content**
Lagrange densities, symmetries and conservation laws, Feynman rules, cross sections, elementary processes in QED, spontaneous symmetry breaking, Higgs mechanism, Standard Model of particle physics, decay rates, Higgs boson phenomenology

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**
Basic knowledge in quantum mechanics I and II

**Literature**
Will be provided in the first lecture.
4.105 Module: Inversion and Tomography [M-PHYS-102368]

**Responsibility:**
Prof. Dr. Thomas Bohlen
apl. Prof. Dr. Joachim Ritter

**Organisation:**
KIT Department of Physics

**Part of:**
Second Major in Physics: Geophysics

**Credits:**
8

**Grading scale:**
Grade to a tenth

**Recurrence:**
Each summer term

**Duration:**
1 term

**Language:**
English

**Level:**
4

**Version:**
2

**Mandatory**

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<td>Bohlen, Ritter</td>
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**Competence Certificate**

To pass the module, an oral exam must be passed (approx. 20 min). As prerequisites the examinations of other type must be passed, based on successful participation of the exercises. Students write reports on their exercise work. These reports are rated. The necessary number of points is explained at the beginning of the individual exercises.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102658 - Inversion and Tomography (Minor) must not have been started.

**Competence Goal**

The students understand how to invert data to achieve a model of physical parameters. The students realize that seismic waves can be treated in different waves: full waveform, finite-frequency approximations (banana-doughnut theory) and rays. From this they understand how seismic images can be constructed and interpreted. Students are able to evaluate inversion models based on error bonds, resolution matrices and reconstruction tests. They know the complete chain of tomography: data pre-processing, parameterization, inversion, model assessment and interpretation. The students are used to read scientific papers on inversion and tomography and to discuss questions on these papers. Finally the students are able to understand basic inverse problems and read more advanced texts. Practically, the students understand how to code simple problems with Matlab or possibly Python. The students know how to analyze inverse problems using singular value decomposition and other methods.

**Content**

- Fundamentals of tomography
- Application of seismic tomography
- Regional to global seismic tomography
- Analysis of tomography problems
- Fundamentals in seismic inversion
- Application of linear and non-linear inversion

**Module grade calculation**

The grade of the module results from grade of the oral exam.

**Workload**

240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

**Recommendation**

Knowledge on fundamentals of seismology and understanding of mathematics, especially matrix calculus. Fundamental skills in Linux, Matlab and computing in general.

**Literature**

### Module: Inversion and Tomography (Minor) [M-PHYS-102658]

**Responsible:** Prof. Dr. Thomas Bohlen  
apl. Prof. Dr. Joachim Ritter  

**Organisation:** KIT Department of Physics  

**Part of:** Minor in Physics: Geophysics  

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**Mandatory**

| T-PHYS-105572 | Inversion and Tomography (Minor) | 8 CR | Bohlen, Ritter |

**Competence Certificate**

To pass the module, the examinations of other type must be passed, based on successful participation of the exercises. Students write reports on their exercise work. These reports are rated. The necessary number of points is explained at the beginning of the individual exercises.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102368 - Inversion and Tomography must not have been started.

**Competence Goal**

The students understand how to invert data to achieve a model of physical parameters. The students realize that seismic waves can be treated in different waves: full waveform, finite-frequency approximations (banana-doughnut theory) and rays. From this they understand how seismic images can be constructed and interpreted. Students are able to evaluate inversion models based on error bonds, resolution matrices and reconstruction tests. They know the complete chain of tomography: data pre-processing, parameterization, inversion, model assessment and interpretation. The students are used to read scientific papers on inversion and tomography and to discuss questions on these papers. Finally the students are able to understand basic inverse problems and read more advanced texts. Practically, the students understand how to code simple problems with Matlab or possibly Python. The students know how to analyze inverse problems using singular value decomposition and other methods.

**Content**

- Fundamentals of tomography  
- Application of seismic tomography  
- Regional to global seismic tomography  
- Analysis of tomography problems  
- Fundamentals in seismic inversion  
- Application of linear and non-linear inversion

**Module grade calculation**

The module is ungraded

**Workload**

240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

**Recommendation**

Knowledge on fundamentals of seismology and understanding of mathematics, especially matrix calculus. Fundamental skills in Linux, Matlab and computing in general.

**Literature**

4.107 Module: Master's Thesis [M-PHYS-106481]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** Master's Thesis

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**Mandatory**

| T-PHYS-113096 | Master's Thesis | 30 CR | Studiendekan Physik |

**Prerequisites**

The modules "Specialisation" and "Introduction to Research Methods" have been passed.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-101396 - Specialization Phase must have been passed.
2. The module M-PHYS-101397 - Introduction to Scientific Methods must have been passed.
Module: Mathematical Methods of Theoretical Physics (two hours per week) [M-PHYS-105834]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Theoretical Particle Physics
- Second Major in Physics: Condensed Matter Theory

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**Mandatory**

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<td>Mathematical Methods of Theoretical Physics (two hours per week)</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105835 - Mathematical Methods of Theoretical Physics (two hours per week) (Minor) must not have been started.

**Competence Goal**

Students understand the concepts of functional analysis and function theory and can apply them to problems in theoretical physics. This includes solving differential equations and complex integrals.

**Content**


**Workload**

240 h consisting of attendance time (60 h), wrap-up of the lecture, working on the exercises and preparation of the exam (180 h)

**Recommendation**

The secure mastery of the material from HM1-HM3 is useful.
Module: Mathematical Methods of Theoretical Physics (two hours per week) (Minor) [M-PHYS-105835]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-105834 - Mathematical Methods of Theoretical Physics (two hours per week) must not have been started.

**Competence Goal**
Students understand the concepts of functional analysis and function theory and can apply them to problems in theoretical physics. This includes solving differential equations and complex integrals.

**Content**

**Workload**
240 h consisting of attendance time (60 h), wrap-up of the lecture and working on the exercises (180 h)

**Recommendation**
The secure mastery of the material from HM1-HM3 is useful
4.110 Module: Measurement Methods and Techniques in Experimental Physics, with ext. Exercises [M-PHYS-102517]

**Responsible:** Dr. Beate Bornschein
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102518 - Measurement Methods and Techniques in Experimental Physics, without ext. Exercises must not have been started.
2. The module M-PHYS-102519 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Students will be able to select suitable measurement methods and measuring instruments, evaluate measured values and calculate measurement uncertainties. The students learn a practical example measurement task in the laboratory.

**Content**

The lecture is intended to facilitate the introduction to experimental work in a laboratory. The aim is for students to gain an overview of a wide range of important measurement methods and experimental techniques and to be able to apply the knowledge they have acquired to practical measurement tasks in examples. The focus here is on the one hand on the methodical procedure for selecting the optimum measurement procedure and on the other hand on the evaluation of measurements including the consideration of measurement uncertainties. Furthermore, the lecture shall contribute to a better communication between engineers, physicists and physicists (e.g. the engineer talks about the measurement uncertainty budget according to GUM and the physicist wonders what that is all about) and thus promote the integration of the young professionals into the mixed teams of technicians, engineers, physicists and physicists which are so typical for KIT.

Among others, the following topics will be covered:

- Measuring instruments and their accuracy classes, calculation of measurement uncertainties according to GUM and determination of a confidence interval, methods of (low) temperature measurement, introduction to vacuum technology including leak detection technology, methods of magnetic field measurement and mass flow measurement, introduction to radiation measurement technology and dosimetry, as well as reading flow diagrams.

Lecture and exercises take place as a 5-day block course at the end of the semester (3 SWS) and can be supplemented by a block practical course (1 SWS, by arrangement).

**Workload**

240 h consisting of attendance time (45 h), wrap-up of the lecture incl. exam preparation and working on the exercises, additionally the internship with 24 h attendance time and 16 h post-processing.
**Recommendation**
Interest in experimental physics

**Literature**
Will be mentioned in the lecture.
Module: Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor) [M-PHYS-102519]

**Responsible:** Dr. Beate Bornschein  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:**  
- Minor in Physics: Experimental Particle Physics  
- Minor in Physics: Experimental Astroparticle Physics

**Credits**  
8

**Grading scale**  
pass/fail

**Recurrence**  
Irregular

**Duration**  
1 term

**Language**  
German

**Level**  
4

**Version**  
1

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<td>Drexlin, Hartmann, Valerius</td>
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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102517 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-102518 - Measurement Methods and Techniques in Experimental Physics, without ext. Exercises must not have been started.

**Competence Goal**  
Students will be able to select suitable measurement methods and measuring instruments, evaluate measured values and calculate measurement uncertainties. The students learn a practical example measurement task in the laboratory.

**Content**  
The lecture is intended to facilitate the introduction to experimental work in a laboratory. The aim is for students to gain an overview of a wide range of important measurement methods and experimental techniques and to be able to apply the knowledge they have acquired to practical measurement tasks in examples. The focus here is on the one hand on the methodical procedure for selecting the optimal measurement procedure and on the other hand on the evaluation of measurements including the consideration of measurement uncertainties. Furthermore, the lecture shall contribute to a better communication between engineers, physicists and physicists (e.g. the engineer talks about the measurement uncertainty budget according to GUM and the physicist wonders what that is all about) and thus promote the integration of the young professionals into the mixed teams of technicians, engineers, physicists and physicists which are so typical for KIT.

Among others, the following topics will be covered:

- Measuring instruments and their accuracy classes, calculation of measurement uncertainties according to GUM and determination of a confidence interval, methods of (low) temperature measurement, introduction to vacuum technology including leak detection technology, methods of magnetic field measurement and mass flow measurement, introduction to radiation measurement technology and dosimetry, as well as reading flow diagrams.

- Lecture and exercises take place as a 5-day block course at the end of the semester (3 SWS) and can be supplemented by a block practical course (1 SWS, by arrangement).

**Workload**  
240 h consisting of attendance time (45 h), wrap-up of the lecture and work on the exercises, plus the internship with 24 h attendance time and 16 h wrap-up.

**Recommendation**  
Interest in experimental physics

**Literature**  
Will be mentioned in the lecture.
4.112 Module: Measurement Methods and Techniques in Experimental Physics, without ext. Exercises [M-PHYS-102518]

**Responsible:** Dr. Beate Bornschein
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

### Credits

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**Measuring Methods and Techniques in Experimental Physics, without ext. Exercises**

**6 CR**

Drexlin, Hartmann, Valerius

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102517** - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises must not have been started.
2. The module **M-PHYS-102519** - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Students will be able to select suitable measurement methods and measuring instruments, evaluate measured values and calculate measurement uncertainties. The students learn a practical example measurement task in the laboratory.

**Content**

The lecture is intended to facilitate the introduction to experimental work in a laboratory. The aim is for students to gain an overview of a wide range of important measurement methods and experimental techniques and to be able to apply the knowledge they have acquired to practical measurement tasks in examples. The focus here is on the one hand on the methodical procedure for selecting the optimal measurement procedure and on the other hand on the evaluation of measurements including the consideration of measurement uncertainties. Furthermore, the lecture shall contribute to a better communication between engineers, physicists and physicists (e.g. the engineer talks about the measurement uncertainty budget according to GUM and the physicist wonders what that is all about) and thus promote the integration of the young professionals into the mixed teams of technicians, engineers, physicists and physicists which are so typical for KIT.

Among others, the following topics will be covered:

- Measuring instruments and their accuracy classes, calculation of measurement uncertainties according to GUM and determination of a confidence interval
- Methods of (low) temperature measurement
- Introduction to vacuum technology including leak detection technology
- Methods of magnetic field measurement and mass flow measurement
- Introduction to radiation measurement technology and dosimetry, as well as reading flow diagrams

Lecture and exercises take place as a 5-day block course at the end of the semester (3 SWS).

**Workload**

180 h consisting of attendance time (45 h), wrap-up of the lecture incl. exam preparation and working on the exercises.

**Recommendation**

Interest in experimental physics
Literature
Will be mentioned in the lecture.
4.113 Module: Measurement Methods and Techniques in Experimental Physics, without ext. Exercises (Minor) [M-PHYS-103194]

**Responsible:** Dr. Beate Bornschein  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:**  
Minor in Physics: Experimental Particle Physics  
Minor in Physics: Experimental Astroparticle Physics

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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102517 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises must not have been started.
2. The module M-PHYS-102519 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102518 - Measurement Methods and Techniques in Experimental Physics, without ext. Exercises must not have been started.

**Competence Goal**

Students will be able to select suitable measurement methods and measuring instruments, evaluate measured values and calculate measurement uncertainties. The students learn a practical example measurement task in the laboratory.

**Content**

The lecture is intended to facilitate the introduction to experimental work in a laboratory. The aim is for students to gain an overview of a wide range of important measurement methods and experimental techniques and to be able to apply the knowledge they have acquired to practical measurement tasks in examples. The focus here is on the one hand on the methodical procedure for selecting the optimum measurement procedure and on the other hand on the evaluation of measurements including the consideration of measurement uncertainties. Furthermore, the lecture shall contribute to a better communication between engineers, physicists and physicists (e.g. the engineer talks about the measurement uncertainty budget according to GUM and the physicist wonders what that is all about) and thus promote the integration of the young professionals into the mixed teams of technicians, engineers, physicists and physicists which are so typical for KIT.

Among others, the following topics will be covered: measuring instruments and their accuracy classes, calculation of measurement uncertainties according to GUM and determination of a confidence interval, methods of (low) temperature measurement, introduction to vacuum technology including leak detection technology, methods of magnetic field measurement and mass flow measurement, introduction to radiation measurement technology and dosimetry, as well as reading flow diagrams.

Lecture and exercises take place as a 5-day block course at the end of the semester (3 SWS).

**Workload**

180 h consisting of attendance time (45 h), wrap-up of the lecture and work on the exercises (135 h)

**Recommendation**  
Interest in experimental physics

**Literature**

Will be mentioned in the lecture.
Module: Microscale Fluid Mechanics [M-MACH-106539]

**Responsible:** Dr.-Ing. Philipp Marthaler

**Organisation:** KIT Department of Mechanical Engineering

**Part of:** Major in Physics: Nanophysics (Elective Nanophysics)
Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**
Oral examination, duration: 30 minutes

**Competence Goal**
After this course, the participants can

1. identify microfluidic and/or electrochemical problems
2. describe those phenomena with the respective terminology and classify them as either Stokes flow, electrohydrodynamic or electrokinetic
3. recognize and apply the appropriate modeling approaches and solution methods
4. analyze the multiphysical and multiscale behavior and discuss the influence of different effects, such as electric forces, surface tension or electric boundary layers
5. assess the importance of these effects in the context of biological phenomena and evaluate design choices in microfluidic devices

**Content**
The lecture covers microfluidic phenomena, particularly Stokes flow and electrical phenomena that occur in fluids. Understanding the mentioned effects is crucial for the development of microfluidic systems with application fields ranging from clinical diagnostics to cell research and environmental monitoring. The basic operations performed in microsystems are particle separation and mixing, chemical analyses, characterization of biological samples, and cell capturing. The sample environment is in fluid form, in the case of fluid samples multiphase phenomena occur.

The lecture gives an overview of the basic physics, i.e., Stokes flow, analysis of hydraulic circuits, surface tension effects, transport of passive scalars, electroosmosis and electrophoresis, structure of the electric double layer, electrokinetics, the Taylor-Melcher model for the description of droplets under the influence of an electric field.

Phenomena with electric boundary layers are discussed using asymptotic methods that are introduced in the lecture. A basic understanding of fluid mechanics and differential equations is required.
### 4.115 Module: Modern Methods of Data Analysis, with ext. Exercises [M-PHYS-102127]

| Responsible          | Prof. Dr. Günter Quast  
<table>
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<tr>
<td>PD Dr. Roger Wolf</td>
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<td>KIT Department of Physics</td>
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| Part of              | Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
|                      | Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)  
|                      | Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
|                      | Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics) |
| Credits              | 8                        |
| Grading scale        | Grade to a tenth         |
| Recurrence           | Each summer term         |
| Duration             | 1 term                   |
| Language             | German                   |
| Level                | 4                        |
| Version              | 1                        |

| Mandatory            | T-PHYS-102495             |
|                      | Modern Methods of Data Analysis, with ext. Exercises |
|                      | 8 CR Quast, Wolf          |

#### Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

#### Prerequisites
none

#### Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102125 - Modern Methods of Data Analysis, without ext. Exercises must not have been started.
2. The module M-PHYS-102126 - Modern Methods of Data Analysis, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102128 - Modern Methods of Data Analysis, with ext. Exercises (Minor) must not have been started.

#### Competence Goal
Students will be able to formulate fundamentals of statistical data analysis, apply modern methods of data analysis to physical problems, and use and further develop tools for data analysis. On this basis, students are enabled to question and evaluate the use of statistical methods in science and society. In the extended exercises, the material is deepened by treating a problem originating from research practice.

#### Content
Fundamentals of probability, probability distributions, Monte Carlo methods, parameter estimation, numerical optimization, convolution and deconvolution, hypothesis testing, confidence intervals, multivariate classification, time series analysis, and filtering.

#### Workload
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and working on the exercises (180 hours).

#### Recommendation
Basic knowledge of statistical data analysis, such as that taught in the undergraduate course Computer Use in Physics, is desirable.

#### Literature
- G.Cowan: Statistical Data Analysis, Oxford University Press
- G.Bohm, G.Zech: Einführung in Statistik und Messwertanalyse für Physiker, DESYeBook
- V.Bloobel, E.Lohrmann: Statistische und numerische Methoden der Datenanalyse, DESYeBook
- S.Brandt: Datenanalyse, Spektrum
- T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer
Module: Modern Methods of Data Analysis, with ext. Exercises (Minor) [M-PHYS-102128]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:**  
- Minor in Physics: Experimental Particle Physics  
- Minor in Physics: Experimental Astroparticle Physics

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**Mandatory**

| T-PHYS-102496 | Modern Methods of Data Analysis, with ext. Exercises (Minor) | 8 CR | Quast, Wolf |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module **M-PHYS-102125** - Modern Methods of Data Analysis, without ext. Exercises must not have been started.
2. The module **M-PHYS-102126** - Modern Methods of Data Analysis, without ext. Exercises (Minor) must not have been started.
3. The module **M-PHYS-102127** - Modern Methods of Data Analysis, with ext. Exercises must not have been started.

**Competence Goal**
Students will be able to formulate fundamentals of statistical data analysis, apply modern methods of data analysis to physical problems, and use and further develop tools for data analysis. On this basis, students are enabled to question and evaluate the use of statistical methods in science and society. In the extended exercises, the material is deepened by treating a problem originating from research practice.

**Content**
Fundamentals of probability, probability distributions, Monte Carlo methods, parameter estimation, numerical optimization, convolution and deconvolution, hypothesis testing, confidence intervals, multivariate classification, time series analysis, and filtering.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**
Basic knowledge of statistical data analysis, such as that taught in the undergraduate course Computer Use in Physics, is desirable.

**Literature**

- G.Cowan: Statistical Data Analysis, Oxford University Press  
- G.Bohm, G.Zech: Einführung in Statistik und Messwertanalyse für Physiker, DESYeBook  
- V.Blobel, E.Lohrmann: Statistische und numerische Methoden der Datenanalyse, DESYeBook  
- S.Brandt: Datenanalyse, Spektrum  
- T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer
4.117 Module: Modern Methods of Data Analysis, without ext. Exercises [M-PHYS-102125]

**Responsible:** Prof. Dr. Günter Quast
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)

**Credits** 6

**Grading scale** Grade to a tenth

**Recurrence** Each summer term

**Duration** 1 term

**Language** German

**Level** 4

**Version** 1

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102126 - Modern Methods of Data Analysis, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102127 - Modern Methods of Data Analysis, with ext. Exercises must not have been started.
3. The module M-PHYS-102128 - Modern Methods of Data Analysis, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Students will be able to formulate fundamentals of statistical data analysis, apply modern methods of data analysis to physical problems, and use and further develop tools for data analysis. On this basis, students are enabled to question and evaluate the use of statistical methods in science and society.

**Content**

Fundamentals of probability, probability distributions, Monte Carlo methods, parameter estimation, numerical optimization, convolution and deconvolution, hypothesis testing, confidence intervals, multivariate classification, time series analysis, and filtering.

**Workload**

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and working on the exercises (135 hours).

**Recommendation**

Basic knowledge of statistical data analysis, such as that taught in the undergraduate course Computer Use in Physics, is desirable.

**Literature**

- G.Cowan: Statistical Data Analysis, Oxford University Press
- G.Bohm, G.Zech: Einführung in Statistik und Messwertanalyse für Physiker, DESYeBook
- V.Bloobel, E.Lohrmann: Statistische und numerische Methoden der Datenanalyse, DESYeBook
- S.Brandt: Datenanalyse, Spektrum
- T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer
Module: Modern Methods of Data Analysis, without ext. Exercises (Minor) [M-PHYS-102126]

**Responsible:** Prof. Dr. Günter Quast
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Experimental Particle Physics
- Minor in Physics: Experimental Astroparticle Physics

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**Credits:** 6
**Grading scale:** pass/fail
**Recurrence:** Each summer term
**Duration:** 1 term
**Language:** German
**Level:** 4
**Version:** 1

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**Mandatory**

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102125 - Modern Methods of Data Analysis, without ext. Exercises must not have been started.
2. The module M-PHYS-102127 - Modern Methods of Data Analysis, with ext. Exercises must not have been started.
3. The module M-PHYS-102128 - Modern Methods of Data Analysis, with ext. Exercises (Minor) must not have been started.

**Competence Goal**
Students will be able to formulate fundamentals of statistical data analysis, apply modern methods of data analysis to physical problems, and use and further develop tools for data analysis. On this basis, students are enabled to question and evaluate the use of statistical methods in science and society.

**Content**
Fundamentals of probability, probability distributions, Monte Carlo methods, parameter estimation, numerical optimization, convolution and deconvolution, hypothesis testing, confidence intervals, multivariate classification, time series analysis, and filtering.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of lecture and completion of exercises (135 hours).

**Recommendation**
Basic knowledge of statistical data analysis, such as that taught in the undergraduate course Computer Use in Physics, is desirable.

**Literature**

- G.Cowan: Statistical Data Analysis, Oxford University Press
- G.Bohm, G.Zech: Einführung in Statistik und Messwertanalyse für Physiker, DESYeBook
- V.Blobel, E.Lohrmann: Statistische und numerische Methoden der Datenanalyse, DESYeBook
- S.Brandt: Datenanalyse, Spektrum
- T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer
Module: Modern Methods of Spectroscopy: Applications in Astroparticle Physics [M-PHYS-106047]

Responsible: Prof. Dr. Guido Drexlin
              Prof. Dr. Kathrin Valerius

Organisation: KIT Department of Physics

Part of: Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
          Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
          Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)
          Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)
          Minor in Physics: Experimental Particle Physics
          Minor in Physics: Experimental Astroparticle Physics

Credits 2
Grading scale pass/fail
Recurrence Each term
Duration 1 term
Language English
Level 4
Version 1

Mandatory

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<td>Modern Methods of Spectroscopy: Applications in Astroparticle Physics</td>
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Competence Certificate
Regular attendance during the block course is required. Successful participation in the course is certified by a preparatory talk introducing the basics, as well as by a final talk on the implementation and results from the subgroups.

Prerequisites
None

Competence Goal
The students are able to apply spectroscopic methods in astro-particle physics. They know how to plan and execute tasks at a large-scale research project from astro-particle physics in teamwork. Furthermore they are able to prepare and present project-specific basic principles as well as own results in a short talk.

Content
Main focus:
- Precision electron spectroscopy with a MAC-E filter spectrometer.
- Tritium process monitoring using optical spectroscopic methods: (i) sample preparation, (ii) processing, and (iii) performing spectroscopic measurements

Further topics:
- Vacuum technology
- Handling of radioactive samples
- Radiochemical properties of tritium
- Superconducting and normal conducting magnets
- Measurement of magnetic fields from mT to T
- Cryogenic fluids in the lab
- High voltage techniques
- Detector technologies & signal processing
- Signal & background

Annotation
MSc Physics: This module cannot be used concurrently with an advanced seminar in the physics major. The same regulation applies to the second major in physics.

Workload
60 h consisting of 1x day introduction with short seminar talks, 5x days in the lab and 1x day concluding presentation of results.

Recommendation
Fundamentals of classical electrodynamics, optical spectroscopy, thermodynamics, atomic, nuclear and particle physics, measurement methods and techniques in experimental physics, astroparticle physics, and cosmology.
Literature

4.120 Module: Molecular Electronics [M-PHYS-104540]

**Responsible:** Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104541 - Molecular Electronics (Minor) must not have been started.

**Competence Goal**

Students acquire knowledge in the field of electronic transport in molecular systems, learn basic concepts of charge, spin and heat transport in nanoscopic systems, as well as their dynamics. They acquire knowledge on the state of the art of research and application of molecular electronics.

**Content**

Molecular bonding, molecular orbitals, localization and delocalization of charge carriers, adsorption and electronic interaction between molecules and conductors, self-energy, Landauer-Büttiker charge transport, spin transport, spin-orbit interaction, Kondo effect, Steven's operators and zero-field splitting, heat transport, Seebeck effect, memrisors.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (135 hours)

**Recommendation**

Basic knowledge of classical electromagnetism, quantum mechanics, solid state physics.

**Literature**

Will be mentioned in the lecture.
Module: Molecular Electronics (Minor) [M-PHYS-104541]

Responsible: Prof. Dr. Wulf Wulfhekel
Organisation: KIT Department of Physics
Part of: Minor in Physics: Condensed Matter
Minor in Physics: Nanophysics

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Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-104540 - Molecular Electronics must not have been started.

Competence Goal
Students acquire knowledge in the field of electronic transport in molecular systems, learn basic concepts of charge, spin and heat transport in nanoscopic systems, as well as their dynamics. They acquire knowledge on the state of the art of research and application of molecular electronics.

Content
Molecular bonding, molecular orbitals, localization and delocalization of charge carriers, adsorption and electronic interaction between molecules and conductors, self-energy, Landauer-Büttiker charge transport, spin transport, spin-orbit interaction, Kondo effect, Steven's operators and zero-field splitting, heat transport, Seebeck effect, memrisors.

Workload
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and work on the exercises (135 hours).

Recommendation
Basic knowledge of classical electromagnetism, quantum mechanics, solid state physics.

Literature
Will be mentioned in the lecture.
Module: Molecular Spectroscopy [M-PHYS-102337]

**Responsible:** apl. Prof. Dr. Andreas-Neil Unterreiner

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Optics and Photonics (Elective Optics and Photonics)
Second Major in Physics: Optics and Photonics

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**Mandatory**

| T-CHEMBIO-104639 | Molecular Spectroscopy | 6 CR | Unterreiner |

**Competence Certificate**

Written exam. Usually 120 minutes.

**Prerequisites**

none

**Competence Goal**

The students receive an in-depth overview of spectroscopic methods as well as the corresponding theoretical foundations, e.g. time-dependent Schrödinger equation and perturbation calculus. In addition, they will be introduced to experimental realizations of spectroscopic experiments so that they can design them independently, understand the emergence of the spectra as well as the underlying principles, such as selection rules, in the context of a quantum mechanical description and use them in all areas of chemistry for the characterization of molecules.

**Content**

Introduction (including electromagnetic radiation, Einstein coefficients), quantum mechanical description of light absorption (perturbation theory, coherent excitation, line shapes), magnetic resonance spectroscopy, rotational spectroscopy, rotational vibrational spectroscopy, Raman spectroscopy, electronic spectroscopy, luminescence, photoelectron spectroscopy.

**Workload**

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Literature**

For example:

- Haken, Wolf: Molekülphysik und Quantenchemie, Springer Verlag Berlin Heidelberg 2006
- Hollas: Moderne Methoden der Spektroskopie, Vieweg, 1995
Module: Monte Carlo Event Generators [M-PHYS-104860]

**Responsible:** PD Dr. Stefan Gieseke  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
- Second Major in Physics: Theoretical Particle Physics

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-104861 - Monte Carlo Event Generators (Minor) must not have been started.

**Competence Goal**  
The students will acquire an overview of the physics concepts that allow the simulation of collisions of highly energetic elementary particles at colliders. The students will be able to understand approximations of perturbative Quantum Chromodynamics as they are needed to construct a parton shower. The students will be able to write their own parton shower simulation as a toy model that covers the main features of general Monte-Carlo simulation programs. The students will apply non-perturbative models of strong interactions to explain the hadronization of particles that carry colour charge. In exercise-sessions they will learn to apply the elements of the underlying Monte Carlo algorithms in terms of practical programming problems.

**Content**
- Monte Carlo Method
- Hard matrix elements from Feynman Diagrams
- Parton showers
- Hadronization
- Hadronic interactions in terms of multiple partonic interactions
- Higher order corrections

**Workload**  
180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (135 hours).

**Recommendation**  
Basic knowledge of Particle Physics is recommended

**Literature**
- Ellis, Stirling, Webber, "QCD and Collider Physics", Cambridge UP.
- Dissertori, Knowles, Schmelling, "Quantum Chromodynamics", Oxford UP
- Field, "Applications of Perturbative Quantum Chromodynamics (Frontiers in Physics)"
4.124 Module: Monte Carlo Event Generators (Minor) [M-PHYS-104861]

**Responsible:** PD Dr. Stefan Gieseke

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-109893 | Monte Carlo Event Generators (Minor) | 6 CR | Gieseke |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
one

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104860 - Monte Carlo Event Generators must not have been started.

**Competence Goal**
The students will acquire an overview of the physics concepts that allow the simulation of collisions of highly energetic elementary particles at colliders. The students will be able to understand approximations of perturbative Quantum Chromodynamics as they are needed to construct a parton shower. The students will be able to write their own parton shower simulation as a toy model that covers the main features of general Monte-Carlo simulation programs. The students will apply non-perturbative models of strong interactions to explain the hadronization of particles that carry colour charge. In exercise-sessions they will learn to apply the elements of the underlying Monte Carlo algorithms in terms of practical programming problems.

**Content**
- Monte Carlo Method
- Hard matrix elements from Feynman Diagrams
- Parton showers
- Hadronization
- Hadronic interactions in terms of multiple partonic interactions
- Higher order corrections

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of lecture and completion of exercises (135 hours).

**Recommendation**
Basic knowledge of Particle Physics is recommended

**Literature**
- Ellis, Stirling, Webber, "QCD and Collider Physics", Cambridge UP.
- Dissertori, Knowles, Schnellling, "Quantum Chromodynamics", Oxford UP
- Field, "Applications of Perturbative Quantum Chromodynamics (Frontiers in Physics)"
Module: Nanomaterials, with Exercises [M-PHYS-105068]

**Responsible:** Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Major in Physics: Nanophysics (Elective Nanophysics)  
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)

**Credits**: 8  
**Grading scale**: Grade to a tenth  
**Recurrence**: Each winter term  
**Duration**: 1 term  
**Language**: English  
**Level**: 4  
**Version**: 1

**Mandatory**

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-105069 - Nanomaterials, with Exercises (Minor) must not have been started.
2. The module M-PHYS-105071 - Nanomaterials, without Exercises must not have been started.

**Competence Goal**  
The field of nanomaterials is a very active area of research driven by the need for novel materials with enhanced functional properties. Many of these have had and continue to have profound impact in technological applications. In this class the students will acquire an understanding of the various aspects of nanomaterials that lead to enhanced properties with an emphasis on nanoparticle systems. The students will develop a clear knowledge of methods for the fabrication of nanomaterials, their properties (optical, magnetic and electrical) as well as some of their applications. In order to gain some insights to current research problems the tutorial will be organized as a journal club, with the students presenting and discussing selected research articles.

**Content**  
After a general introduction to nanostructured materials with an emphasis on nanoparticle based systems (Reduced dimensionality, size effects on properties) the course will cover the following topics:

1. Synthesis of clusters, nanoparticles and nanocomposites (Free-jet expansion, Physical vapor deposition, chemical vapor deposition, selection of chemical routes).
2. Optical properties (Quantum dots, luminescence, plasmons, measurement techniques, applications),
3. Magnetic properties (Superparamagnetism, measurement techniques, applications),
4. Transport properties (Superconductivity and magneto transport with an emphasis on granular systems),
5. Synthesis, properties and applications of nanowires and 2d materials

**Workload**  
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

**Recommendation**  
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is required.
Literature

- R.K. Goyal, Nanomaterials and nanocomposites: synthesis, properties, characterization techniques and applications, CRC Press 2018
- A.S. Edelstein (Ed.), Nanomaterials: Synthesis, properties, applications
- D. Vollath. Nanomaterials: An Introduction to Synthesis, Properties and Applications
4.126 Module: Nanomaterials, with Exercises (Minor) [M-PHYS-105069]

Responsible: Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer  

Organisation: KIT Department of Physics  
Part of: Minor in Physics: Condensed Matter  
Minor in Physics: Nanophysics

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Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-105068 - Nanomaterials, with Exercises must not have been started.
2. The module M-PHYS-105071 - Nanomaterials, without Exercises must not have been started.

Competence Goal
The field of nanomaterials is a very active area of research driven by the need for novel materials with enhanced functional properties. Many of these have had and continue to have profound impact in technological applications. In this class the students will acquire an understanding of the various aspects of nanomaterials that lead to enhanced properties with an emphasis on nanoparticulate systems. The students will develop a clear knowledge of methods for the fabrication of nanomaterials, their properties (optical, magnetic and electrical) as well as some of their applications. In order to gain some insights to current research problems the tutorial will be organized as a journal club, with the students presenting and discussing selected research articles.

Content
After a general introduction to nanostructured materials with an emphasis on nanoparticle based systems (Reduced dimensionality, size effects on properties) the course will cover the following topics:

1. Synthesis of clusters, nanoparticles and nanocomposites (Free-jet expansion, Physical vapor deposition, chemical vapor deposition, selection of chemical routes).
2. Optical properties (Quantum dots, luminescence, plasmons, measurement techniques, applications),
3. Magnetic properties (Superparamagnetism, measurement techniques, applications),
4. Transport properties (Superconductivity and magneto transport with an emphasis on granular systems),
5. Synthesis, properties and applications of nanowires and 2d materials

Workload
240 hours consisting of attendance time (60 hours), wrap-up of lecture and preparation of exercises (180 hours).

Recommendation
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is required.

Literature
- R.K. Goyal, Nanomaterials and nanocomposites : synthesis, properties, characterization techniques and applications, CRC Press 2018
- A.S. Edelstein (Ed.), Nanomaterials:Synthesis, properties, applications
- D. Vollath. Nanomaterials : An Introduction to Synthesis, Properties and Applications
Module: Nanomaterials, without Exercises [M-PHYS-105071]

**Responsible:** Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:***
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

**Credits**: 4  
**Grading scale**: Grade to a tenth  
**Recurrence**: Each winter term  
**Duration**: 1 term  
**Language**: English  
**Level**: 4  
**Version**: 1

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-105068 - Nanomaterials, with Exercises must not have been started.
2. The module M-PHYS-105069 - Nanomaterials, with Exercises (Minor) must not have been started.

**Competence Goal**  
The field of nanomaterials is a very active area of research driven by the need for novel materials with enhanced functional properties. Many of these have had and continue to have profound impact in technological applications. In this class the students will acquire an understanding of the various aspects of nanomaterials that lead to enhanced properties with an emphasis on nanoparticulate systems. The students will develop a clear knowledge of methods for the fabrication of nanomaterials, their properties (optical, magnetic and electrical) as well as some of their applications.

**Content**  
After a general introduction to nanostructured materials with an emphasis on nanoparticle based systems (Reduced dimensionality, size effects on properties) the course will cover the following topics:

1. Synthesis of clusters, nanoparticles and nanocomposites (Free-jet expansion, Physical vapor deposition, chemical vapor deposition, selection of chemical routes).
2. Optical properties (Quantum dots, luminescence, plasmons, measurement techniques, applications),
3. Magnetic properties (Superparamagnetism, measurement techniques, applications),
4. Transport properties (Superconductivity and magneto transport with an emphasis on granular systems),
5. Synthesis, properties and applications of nanowires and 2d materials

**Workload**  
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours).

**Recommendation**  
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is required.

**Literature**

- R.K. Goyal, Nanomaterials and nanocomposites : synthesis, properties, characterization techniques and applications, CRC Press 2018
- A.S. Edelstein (Ed.), Nanomaterials:Synthesis, properties, applications
- D. Vollath. Nanomaterials : An Introduction to Synthesis, Properties and Applications
Module: Nano-Optics [M-PHYS-102146]

**Responsible:** PD Dr. Andreas Naber
**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

**Credits:** 8
**Grading scale:** Grade to a tenth
**Recurrence:** Each winter term
**Duration:** 1 term
**Language:** English
**Level:** 4
**Version:** 1

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**Competence Certificate**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102147 - Nano-Optics (Minor) must not have been started.

**Competence Goal**
The students
- improve their understanding of general principles in electrodynamics and optics
- have a deeper understanding of the theoretical background in optical imaging and its relation to phenomena on a nanoscale
- are familiar with conventional techniques in optical microscopy and make use of their knowledge for the understanding of nano-optical methods
- realize the necessity of completely new experimental concepts to overcome the constraints of classical microscopy in the exploration of optical phenomena beyond the diffraction limit
- understand the basics of different experimental approaches for optical imaging on a nanoscale
- are able to discuss pros and cons of these techniques for applications in different fields of physics and biology
- are aware of the importance of nano-optical methods for the elucidation of long-standing interdisciplinary issues

**Content**
The lecture gives an introduction to theory and instrumentation of advanced methods in optical microscopy. Emphasis is laid on far- and near-field optical techniques with an optical resolution capability on a 10- to 100-nm-scale which is well below the principal limit of classical microscopy. Applications from different scientific disciplines are discussed (e.g., nano-antennas, single-molecule detection, plasmon-polariton propagation on metal surfaces, imaging of biological cell compartments including membranes).

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

**Recommendation**
Basic knowledge in optics

**Literature**
Will be mentioned in the lecture.
4.129 Module: Nano-Optics (Minor) [M-PHYS-102147]

**Responsible:** PD Dr. Andreas Naber

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Nanophysics
- Minor in Physics: Optics and Photonics

### Mandatory

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102146 - Nano-Optics must not have been started.

**Competence Goal**
The students

- improve their understanding of general principles in electrodynamics and optics
- have a deeper understanding of the theoretical background in optical imaging and its relation to phenomena on a nanoscale
- are familiar with conventional techniques in optical microscopy and make use of their knowledge for the understanding of nano-optical methods
- realize the necessity of completely new experimental concepts to overcome the constraints of classical microscopy in the exploration of optical phenomena beyond the diffraction limit
- understand the basics of different experimental approaches for optical imaging on a nanoscale
- are able to discuss pros and cons of these techniques for applications in different fields of physics and biology
- are aware of the importance of nano-optical methods for the elucidation of long-standing interdisciplinary issues

**Content**
The lecture gives an introduction to theory and instrumentation of advanced methods in optical microscopy. Emphasis is laid on far- and near-field optical techniques with an optical resolution capability on a 10- to 100-nm-scale which is well below the principal limit of classical microscopy. Applications from different scientific disciplines are discussed (e.g., nano-antennas, single-molecule detection, plasmon-polariton propagation on metal surfaces, imaging of biological cell compartments including membranes).

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**
Basic knowledge in optics

**Literature**
Will be mentioned in the lecture.
Module: New Light Particles Beyond the Standard Model [M-PHYS-105534]

**Responsible:** Prof. Dr. Ulrich Nierste
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-111115 | New Light Particles Beyond the Standard Model | 8 CR | Nierste, Ziegler |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105582 - New Light Particles Beyond the Standard Model (Minor) must not have been started.
2. The module M-PHYS-105833 - New Light Particles Beyond the Standard Model, without Exercises must not have been started.

**Competence Goal**

Students have a deeper understanding of theoretical concepts such as quantum field theory anomalies, kinetic mixing, effective theories, Goldstone theorem. They understand the strong CP problem and possible solutions, they can construct simple standard model extensions with light bosons, fermions as well as vector particles.

**Content**

This module provides an overview of the theoretical and phenomenological aspects of new light particles beyond the Standard Model. For this purpose, the theoretical foundations of QCD axions, axion-like particles, dark photons, and sterile neutrinos are considered, with a detailed treatment of the theoretical motivation of the QCD axion in particular. The discussion of phenomenology includes possible connections with dark matter, constraints from cosmology and astrophysics, dedicated experimental searches with helioscopes and haloscopes such as CAST or ADMX, and constraints from high-precision experiments such as Belle-II, NA62, XENON1T, and KATRIN. In the exercises accompanying the lectures, the taught contents will be further deepened.

**Workload**

240 h consisting of attendance time (60 h), wrap-up of the lecture, working on the exercises and preparation of the exam (180 h).

**Recommendation**

Familiarity with the Standard Model and Theoretical Particle Physics.

**Literature**

Will be stated on the lecture website and in the lecture itself.
Module: New Light Particles Beyond the Standard Model (Minor) [M-PHYS-105582]

Responsible: Prof. Dr. Ulrich Nierste
Dr. Robert Ziegler

Organisation: KIT Department of Physics

Part of: Minor in Physics: Theoretical Particle Physics

Credits  8
Grading scale  pass/fail
Recurrence  Irregular
Duration  1 term
Language  English
Level  4
Version  3

Mandatory

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Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-105534 - New Light Particles Beyond the Standard Model must not have been started.
2. The module M-PHYS-105833 - New Light Particles Beyond the Standard Model, without Exercises must not have been started.

Competence Goal
The students have a deeper understanding of theoretical concepts such as quantum field theory anomalies, kinetic mixing, effective theories, Goldstone theorem. They understand the strong CP problem and possible solutions, they can construct simple standard model extensions with light bosons, fermions as well as vector particles.

Content
This module provides an overview of the theoretical and phenomenological aspects of new light particles beyond the Standard Model. For this purpose, the theoretical foundations of QCD axions, axion-like particles, dark photons, and sterile neutrinos are considered, with a detailed treatment of the theoretical motivation of the QCD axion in particular. The discussion of phenomenology includes possible connections with dark matter, constraints from cosmology and astrophysics, dedicated experimental searches with helioscopes and haloscopes such as CAST or ADMX, and constraints from high-precision experiments such as Belle-II, NA62, XENON1T, and KATRIN. In the exercises accompanying the lectures, the taught contents will be further deepened.

Workload
240 h consisting of attendance time (60 h), wrap-up of the lecture and working on the exercises (180 h)

Recommendation
Familiarity with the Standard Model and Theoretical Particle Physics.

Literature
Will be stated on the lecture website and in the lecture itself.
Module: New Light Particles Beyond the Standard Model, without Exercises [M-PHYS-105833]

**Responsible:** Prof. Dr. Ulrich Nierste  
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Compeence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105582 - New Light Particles Beyond the Standard Model (Minor) must not have been started.
2. The module M-PHYS-105534 - New Light Particles Beyond the Standard Model must not have been started.

**Competence Goal**

The students gain a deeper understanding of theoretical concepts such as quantum field theory anomalies, kinetic mixing, effective theories, Goldstone theorem. In addition, they understand the strong CP problem and know possible effective solutions. Students will be able to construct simple standard model expansions with light bosons, fermions as well as vector bosons.

**Content**

This module provides an overview of the theoretical and phenomenological aspects of new light particles beyond the Standard Model. For this purpose, the theoretical foundations of QCD axions, axion-like particles, dark photons, and sterile neutrinos are considered, with a detailed treatment of the theoretical motivation of the QCD axion in particular. The discussion of phenomenology includes possible connections with dark matter, constraints from cosmology and astrophysics, dedicated experimental searches with helioscopes and haloscopes such as CAST or ADMX, and constraints from high-precision experiments such as Belle-II, NA62, XENON1T, and KATRIN.

**Workload**

120 h consisting of attendance time (30 h) and wrap-up of the lecture including exam preparation (90 h)

**Recommendation**

Familiarity with the Standard Model and Theoretical Particle Physics.

**Literature**

Will be stated on the lecture website and in the lecture itself.
Module: Nonlinear Optics [M-ETIT-100430]

Responsible: Prof. Dr.-Ing. Christian Koos
Organisation: KIT Department of Electrical Engineering and Information Technology
Part of: Major in Physics: Optics and Photonics (Elective Optics and Photonics)
Second Major in Physics: Optics and Photonics

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Mandatory
T-ETIT-101906 Nonlinear Optics 6 CR Koos

Competence Certificate
The oral exam is offered continuously upon individual appointment.

Prerequisites
none

Competence Goal
The students

- understand and can mathematically describe the effect of basic nonlinear-optical phenomena using optical susceptibility tensors,
- understand and can mathematically describe wave propagation in nonlinear anisotropic materials,
- have an overview and can quantitatively describe common second-order nonlinear effects comprising the electro-optic effect, second-harmonic generation, sum- and difference frequency generation, parametric amplification and optical rectification,
- have an overview and can quantitatively describe the Kerr effect and other common third-order nonlinear effects, comprising self- and cross-phase modulation, four-wave mixing, self-focussing, and third-harmonic generation,
- have an overview and can describe nonlinear-optical interaction in active devices such as semiconductor optical amplifiers
- conceive the basic principles of various phase-matching techniques and can apply them to practical design problems,
- conceive the basic principles of electro-optic modulators, can apply them to practical design problems, and have an overview on state-of-the-art devices,
- conceive the basic principles of third-order nonlinear signal processing and can apply them to practical design problems.

Content

1. The nonlinear optical susceptibility: Maxwell’s equations and constitutive relations, relation between electric field and polarization, formal definition and properties of the nonlinear optical susceptibility tensor,
2. Wave propagation in nonlinear anisotropic materials
3. Second-order nonlinear effects and devices: Linear electro-optic effect / Pockels effect, second-harmonic generation, sum- and difference-frequency generation, phase matching, parametric amplification, optical rectification
4. Third-order nonlinear effects and devices: Nonlinear refractive index and Kerr effect, self- and cross-phase modulation, four-wave mixing, self-focussing, third-harmonic generation
5. Nonlinear effects in active optical devices

Module grade calculation
The module grade is the grade of the oral exam.

There is a bonus system based on the problem sets that are solved during the tutorials: During the term, 3 problem sets will be collected in the tutorial and graded without prior announcement. If for each of these sets more than 70% of the problems have been solved correctly, a bonus of 0.3 grades will be granted on the final mark of the oral exam.

Workload
Approx. 180 h – 30 h lectures, 30 h exercises, 120 h homework and self-studies
Literature
4.134 Module: Non-supersymmetric Extensions of the Standard Model (Minor) [M-PHYS-105639]

**Responsible:** Dr. Monika Blanke  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-111277 | Non-supersymmetric Extensions of the Standard Model (Minor) | 4 CR | Blanke, Nierste |

**Competence Certificate**
Study achievement, ungraded. Active participation in the flipped classroom lectures is the requirement for passing the course.

**Prerequisites**
basic knowledge of quantum field theory and the standard model of particle physics

**Competence Goal**
The students are able to study and understand concepts of modern particle physics, apply their knowledge to related problems and discuss solutions with their peers.

**Content**
This module introduces popular non-supersymmetric extensions of the Standard Model and discusses their phenomenology. Topics include:

- Standard Model and its limitations: electroweak hierarchy problem, flavour problem
- dynamical symmetry breaking and Goldstone bosons
- collective symmetry breaking and Little Higgs models
- composite Higgs models
- partial compositeness and flavour
- extra dimensions and branes
- Randall-Sundrum model, AdS/CFT correspondence

**Annotation**
The module is held in the flipped-classroom format. Materials are provided for self-study. Questions and applications are discussed during the lecture.

**Workload**
120 h consisting of attendance time (30 h) and preparation and wrap-up of the lecture (90 h)

**Literature**
will be announced in the first lecture
4.35 Module: Particle Physics I [M-PHYS-102114]

**Responsible:**
Prof. Dr. Torben Ferber  
Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute  
Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:**
Major in Physics: Experimental Particle Physics (mandatory)  
Second Major in Physics: Experimental Particle Physics (mandatory)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102115 - Particle Physics I (Minor) must not have been started.

**Competence Goal**

Students can classify elementary particles and qualitatively analyze interactions between elementary particles using symmetries, Feynman diagrams and Lagrangian densities. Combining this knowledge with knowledge of elementary particle detection, students will be able to discuss the operation of modern particle physics detectors. Students will be able to interpret current data and figures from the scientific literature on particle physics and present the current state of research and important "open questions". Students will be able to apply techniques of statistical data analysis and Monte Carlo simulation to simple particle physics problems and perform basic characterization of silicon track detectors in the laboratory.

**Content**

Lecture:

- Basic concepts of particle physics
- Detectors and accelerators
- Basics of the Standard Model
- Tests of the electroweak theory
- Flavour physics
- QCD
- Physics at high transverse momenta
- Higgs physics
- Physics of massive neutrinos
- Physics beyond the Standard Model

Practical exercises:

- Current methods of Monte Carlo simulation and data analysis in particle physics.
- Measurements on modern silicon track detectors.

**Annotation**

For students of the KIT Faculty of Computer Science: The exams in this module have to be registered via admissions from ISS (KIT Faculty of Computer Science). For this, an e-mail with matriculation numbers and name of the desired exam to Beratung-inFORMATIK@informatik.kit.edu is sufficient.
**Workload**
approx. 240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (180 hours)

**Recommendation**
Basic knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the bachelor's program in physics.

**Literature**

Additional references will be given in lecture.
4.136 Module: Particle Physics I (Minor) [M-PHYS-102115]

**Responsible:** Prof. Dr. Torben Ferber  
Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute  
Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102114 - Particle Physics I must not have been started.

**Competence Goal**
Students can classify elementary particles and qualitatively analyze interactions between elementary particles using symmetries, Feynman diagrams and Lagrangian densities. Combining this knowledge with knowledge of elementary particle detection, students will be able to discuss the operation of modern particle physics detectors. Students will be able to interpret current data and figures from the scientific literature on particle physics and present the current state of research and important "open questions". Students will be able to apply techniques of statistical data analysis and Monte Carlo simulation to simple particle physics problems and perform basic characterization of silicon track detectors in the laboratory.

**Content**

**Lecture:**

- Basic concepts of particle physics
- Detectors and accelerators
- Basics of the Standard Model
- Tests of the electroweak theory
- Flavour physics
- QCD
- Physics at high transverse momenta
- Higgs physics
- Physics of massive neutrinos
- Physics beyond the Standard Model

**Practical exercises:**

- Current methods of Monte Carlo simulation and data analysis in particle physics.
- Measurements on modern silicon track detectors.

**Workload**

Approx. 240 hours consisting of attendance time (60 hours), follow-up of the lecture and preparation of the exercises (180 hours).
Recommendation
Basic knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the bachelor's program in physics.

Literature

Additional references will be given in lecture.
4.137 Module: Particle Physics II - Flavour Physics, with ext. Exercises [M-PHYS-102422]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)  
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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**Mandatory**

| T-PHYS-104783 | Particle Physics II - Flavour Physics, with ext. Exercises | 8 CR | Ferber, Goldenzweig, Nierste |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102155 - Particle Physics II - Flavour Physics, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-102154 - Particle Physics II - Flavour Physics, without ext. Exercises must not have been started.
3. The module M-PHYS-103183 - Particle Physics II - Flavour Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**  
Students gain a better understanding of the fundamental laws of nature on the precision front of experimental particle physics. Students will learn the underlying concepts, and gain hands-on experience that will contribute to a successful introduction to their own research. In addition, students will be able to understand scientific publications and present them independently to other participants.

**Content**  
Particle accelerators allow the fundamental building blocks and forces of nature to be studied. In addition to the use of ever higher energies, knowledge in this field can also be extended by measurements with ever higher precision. Such precision measurements are successfully performed at CERN and at the Tevatron on multipurpose experiments, as well as in special flavor factories at SLAC or at the SuperKEKB accelerator in Japan.

During the lecture we will present experimental methods and certain key processes - meson mixing, CP violation, rare decays. In the exercise, we will additionally discuss tools for everyday life, such as angular distributions and quantum numbers and information systems on the Internet. In addition, there will be a paper seminar at the end of the semester.

**Workload**  
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**  
Knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the Bachelor's program is assumed.

**Literature**  
Will be mentioned in the lecture.
4.138 Module: Particle Physics II - Flavour Physics, with ext. Exercises (Minor) [M-PHYS-103183]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module **M-PHYS-102155 - Particle Physics II - Flavour Physics, without ext. Exercises (Minor)** must not have been started.
2. The module **M-PHYS-102154 - Particle Physics II - Flavour Physics, without ext. Exercises** must not have been started.
3. The module **M-PHYS-102422 - Particle Physics II - Flavour Physics, with ext. Exercises** must not have been started.

**Competence Goal**
Students gain a better understanding of the fundamental laws of nature on the precision front of experimental particle physics. Students will learn the underlying concepts, and gain hands-on experience that will contribute to a successful introduction to their own research. In addition, students will be able to understand scientific publications and present them independently to other participants.

**Content**
Particle accelerators allow the fundamental building blocks and forces of nature to be studied. In addition to the use of ever higher energies, knowledge in this field can also be extended by measurements with ever higher precision. Such precision measurements are successfully performed at CERN and at the Tevatron on multipurpose experiments, as well as in special flavor factories at SLAC or at the SuperKEKB accelerator in Japan.

During the lecture we will present experimental methods and certain key processes - meson mixing, CP violation, rare decays. In the exercise, we will additionally discuss tools for everyday life, such as angular distributions and quantum numbers and information systems on the Internet. In addition, there will be a paper seminar at the end of the semester.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**
Knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the Bachelor's program is assumed.

**Literature**
Will be mentioned in the lecture.
4.139 Module: Particle Physics II - Flavour Physics, without ext. Exercises [M-PHY-102154]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)  
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

**Credits** 6  
**Grading scale** Grade to a tenth  
**Recurrence** Each winter term  
**Duration** 1 term  
**Language** English  
**Level** 4  
**Version** 1

Mandatory

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHY-102155 - Particle Physics II - Flavour Physics, without ext. Exercises (Minor) must not have been started.
2. The module M-PHY-102422 - Particle Physics II - Flavour Physics, with ext. Exercises must not have been started.
3. The module M-PHY-103183 - Particle Physics II - Flavour Physics, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

Students gain a better understanding of the fundamental laws of nature on the precision front of experimental particle physics. Students learn the underlying concepts, and gain hands-on experience that contributes to a successful introduction to their own research.

**Content**

Particle accelerators allow the fundamental building blocks and forces of nature to be studied. In addition to the use of ever higher energies, knowledge in this field can also be extended by measurements with ever higher precision. Such precision measurements are successfully performed at CERN and at the Tevatron on multipurpose experiments, as well as in special flavor factories at SLAC or at the SuperKEKB accelerator in Japan.

During the lecture we will present experimental methods and certain key processes - meson mixing, CP violation, rare decays. In the exercise we will additionally discuss tools for everyday life, such as angular distributions and quantum numbers and information systems on the internet.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the Bachelor's program is assumed.

**Literature**

Will be mentioned in the lecture.
Module: Particle Physics II - Flavour Physics, without ext. Exercises (Minor) [M-PHYS-102155]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste  

**Organisation:** KIT Department of Physics  

**Part of:** Minor in Physics: Experimental Particle Physics

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**Mandatory**

| T-PHYS-102424 | Particle Physics II - Flavour Physics, without ext. Exercises (Minor) | 6 CR  |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102154 - Particle Physics II - Flavour Physics, without ext. Exercises must not have been started.
2. The module M-PHYS-103183 - Particle Physics II - Flavour Physics, with ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-102422 - Particle Physics II - Flavour Physics, with ext. Exercises must not have been started.

**Competence Goal**
Students gain a better understanding of the fundamental laws of nature on the precision front of experimental particle physics. Students learn the underlying concepts, and gain hands-on experience that contributes to a successful introduction to their own research.

**Content**
Particle accelerators allow the fundamental building blocks and forces of nature to be studied. In addition to the use of ever higher energies, knowledge in this field can also be extended by measurements with ever higher precision. Such precision measurements are successfully performed at CERN and at the Tevatron on multipurpose experiments, as well as in special flavor factories at SLAC or at the SuperKEKB accelerator in Japan.

During the lecture we will present experimental methods and certain key processes - meson mixing, CP violation, rare decays. In the exercise we will additionally discuss tools for everyday life, such as angular distributions and quantum numbers and information systems on the internet.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**
Knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the Bachelor's program is assumed.

**Literature**
Will be mentioned in the lecture.
Module: Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises [M-PHYS-105939]

**Responsible:** Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

The students are able to present the theoretical and experimental basics of physics beyond the standard model of particle physics, together with the most important related measurements. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in physics beyond the standard model. The students solve problems as a team and improve their presentation skills. The students are able to research and analyze scientific publications in the field of particle physics.

**Content**

- Review of the standard model of particle physics (SM)
- Experimental and theoretical motivation for searches beyond the SM
- Selected examples for theories of and searches for physics beyond the SM
- Experimental techniques and modern methods of statistical data analysis

**Workload**

240 hours consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 h)

**Recommendation**

Basic knowledge from the bachelor lectures “Moderne Experimentalphysik III”, “Moderne Theoretische Physik II” and “Rechnernutzung in der Physik” as well as from the master lecture “Particle Physics I” is assumed.
Module: Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises (Minor) [M-PHYS-105940]

**Responsible:** Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Particle Physics

### Credits
8

### Grading scale
pass/fail

### Recurrence
Irregular

### Duration
1 term

### Language
English

### Level
4

### Version
1

### Mandatory

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**Competence Certificate**
The course credit is achieved through successful participation in the exercise. The details will be announced in the first lecture or at the first tutorial.

**Competence Goal**
The students are able to present the theoretical and experimental basics of physics beyond the standard model of particle physics, together with the most important related measurements. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in physics beyond the standard model. The students solve problems as a team and improve their presentation skills. The students are able to research and analyze scientific publications in the field of particle physics.

### Content
- Review of the standard model of particle physics (SM)
- Experimental and theoretical motivation for searches beyond the SM
- Selected examples for theories of and searches for physics beyond the SM
- Experimental techniques and modern methods of statistical data analysis

### Workload
240 hours consisting of attendance time (60 h), wrap-up of the lecture and preparation of the exercises (180 h).

### Recommendation
Basic knowledge from the bachelor lectures “Moderne Experimentalphysik III”, “Moderne Theoretische Physik II” and “Rechnernutzung in der Physik” as well as from the master lecture “Particle Physics I” is assumed.
4.143 Module: Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises [M-PHYS-105937]

**Responsible:** Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

The students are able to present the theoretical and experimental basics of physics beyond the standard model of particle physics, together with the most important related measurements. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in physics beyond the standard model. The students solve problems as a team. The students are able to research and analyze scientific publications in the field of particle physics.

**Content**

- Review of the standard model of particle physics (SM)
- Experimental and theoretical motivation for searches beyond the SM
- Selected examples for theories of and searches for physics beyond the SM
- Experimental techniques and modern methods of statistical data analysis

**Workload**

180 hours consisting of attendance time (45 h), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 h)

**Recommendation**

Basic knowledge from the bachelor lectures “Moderne Experimentalphysik III”, “Moderne Theoretische Physik II” and “Rechnernutzung in der Physik” as well as from the master lecture “Particle Physics I” is assumed.
4.144 Module: Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises (Minor) [M-PHYS-105938]

**Responsible:** Prof. Dr. Markus Klute  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Experimental Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercise. The details will be announced in the first lecture or at the first tutorial.

**Competence Goal**
The students are able to present the theoretical and experimental basics of physics beyond the standard model of particle physics, together with the most important related measurements. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in physics beyond the standard model. The students solve problems as a team. The students are able to research and analyze scientific publications in the field of particle physics.

**Content**
- Review of the standard model of particle physics (SM)  
- Experimental and theoretical motivation for searches beyond the SM  
- Selected examples for theories of and searches for physics beyond the SM  
- Experimental techniques and modern methods of statistical data analysis

**Workload**
180 hours consisting of attendance time (45 h), wrap-up of the lecture and preparation of the exercises (135 h).

**Recommendation**
Basic knowledge from the bachelor lectures “Moderne Experimentalphysik III”, "Moderne Theoretische Physik II" and “Rechnernutzung in der Physik” as well as from the master lecture “Particle Physics I” is assumed.
Module: Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises [M-PHYS-104088]

**M 4.145 Module: Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises [M-PHYS-104088]**

**Responsible:** Prof. Dr. Thomas Müller
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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**Mandatory**

| T-PHYS-108474 | Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises | 8 CR | Müller, Rabbertz |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104086 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises must not have been started.
2. The module M-PHYS-104087 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-104089 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students have in-depth knowledge in a special field of particle physics and gain insights into the current state of research. They know current theoretical concepts and experimental techniques. The participants can solve simple and complex problems in written form or in practical exercises on the computer. They know typical computer-based methods for the simulation of particle-physical processes and for data analysis and have gained experience in more in-depth work with primary literature.

**Content**

Quantum chromodynamics, modern simulation programs and analysis techniques, jet algorithms, jet energy calibration, calculation and measurement of jet effective cross sections, experimental and theoretical corrections and uncertainties, determination of strong interaction constants, recent measurements at hadron colliders, production and decay of top pairs and single top quarks, top properties in the Standard Model, reconstruction of top events, boosted top, connection between top and Higgs physics, search for New Physics with top quarks.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180)

**Recommendation**

Basic knowledge from the courses Modern Experimental Physics III, Modern Theoretical Physics II and Computer Use in Physics from the Bachelor's program and Particle Physics I from the Master's program is assumed.
**Literature**

- Several habilitation theses: W. Wagner (Karlsruhe 2005), A. Quadt (Bonn 2006), F.Fiedler (Munich 2007), M.-A. Pleier (Bonn 2008), D. Wicke (Wuppertal 2009), and recent scientific publications and reviews.
4.146 Module: Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor) [M-PHYS-104089]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104086 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises must not have been started.
2. The module M-PHYS-104087 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-104088 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises must not have been started.

**Competence Goal**
The students have in-depth knowledge in a special field of particle physics and gain insights into the current state of research. They know current theoretical concepts and experimental techniques. The participants can solve simple and complex problems in written form or in practical exercises on the computer. They know typical computer-based methods for the simulation of particle-physical processes and for data analysis and have gained experience in more in-depth work with primary literature.

**Content**
Quantum chromodynamics, modern simulation programs and analysis techniques, jet algorithms, jet energy calibration, calculation and measurement of jet effective cross sections, experimental and theoretical corrections and uncertainties, determination of strong interaction constants, recent measurements at hadron colliders, production and decay of top pairs and single top quarks, top properties in the Standard Model, reconstruction of top events, boosted top, connection between top and Higgs physics, search for New Physics with top quarks.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180).

**Recommendation**
Basic knowledge from the courses Modern Experimental Physics III, Modern Theoretical Physics II and Computer Use in Physics from the Bachelor's program and Particle Physics I from the Master's program is assumed.
Literature

- Several habilitation theses: W. Wagner (Karlsruhe 2005), A. Quadt (Bonn 2006), F. Fiedler (Munich 2007), M.-A. Pleier (Bonn 2008), D. Wicke (Wuppertal 2009).and recent scientific publications and reviews.
Module: Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises [M-PHYS-104086]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz  

**Organisation:** KIT Department of Physics  

**Part of:** Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)  
Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

**Credits:** 6  
**Grading scale:** Grade to a tenth  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** German  
**Level:** 4  
**Version:** 1

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-104087 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-104088 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises must not have been started.
3. The module M-PHYS-104089 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor) must not have been started.

**Competence Goal**  
The students have in-depth knowledge in a special field of particle physics and gain insights into the current state of research. They know current theoretical concepts and experimental techniques. The participants can solve simple problems in written form or in practical exercises on the computer. They know typical computer-based methods for simulating particle-physical processes and for data analysis and have gained experience in working with primary literature.

**Content**  
Quantum chromodynamics, modern simulation programs and analysis techniques, jet algorithms, jet energy calibration, calculation and measurement of jet effective cross sections, experimental and theoretical corrections and uncertainties, determination of strong interaction constants, recent measurements at hadron colliders, production and decay of top pairs and single top quarks, top properties in the Standard Model, reconstruction of top events, boosted top, connection between top and Higgs physics, search for New Physics with top quarks.

**Workload**  
180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**  
Basic knowledge from the courses Modern Experimental Physics III, Modern Theoretical Physics II and Computer Use in Physics from the Bachelor's program and Particle Physics I from the Master's program is assumed.
Literature

- Several habilitation theses: W. Wagner (Karlsruhe 2005), A. Quadt (Bonn 2006), F.Fiedler (Munich 2007), M.-A. Pleier (Bonn 2008), D. Wicke (Wuppertal 2009). and recent scientific publications and reviews.
Module: Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) [M-PHYS-104087]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Experimental Particle Physics

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**Mandatory**

| T-PHYS-108473 | Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) | 6 CR | Müller, Rabbertz |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104086 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises must not have been started.
2. The module M-PHYS-104088 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises must not have been started.
3. The module M-PHYS-104089 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor) must not have been started.

**Competence Goal**
The students have in-depth knowledge in a special field of particle physics and gain insights into the current state of research. They know current theoretical concepts and experimental techniques. The participants can solve simple problems in written form or in practical exercises on the computer. They know typical computer-based methods for simulating particle-physical processes and for data analysis and have gained experience in working with primary literature.

**Content**
Quantum chromodynamics, modern simulation programs and analysis techniques, jet algorithms, jet energy calibration, calculation and measurement of jet effective cross sections, experimental and theoretical corrections and uncertainties, determination of strong interaction constants, recent measurements at hadron colliders, production and decay of top pairs and single top quarks, top properties in the Standard Model, reconstruction of top events, boosted top, connection between top and Higgs physics, search for New Physics with top quarks.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**
Basic knowledge from the courses Modern Experimental Physics III, Modern Theoretical Physics II and Computer Use in Physics from the Bachelor's program and Particle Physics I from the Master's program is assumed.
Literature

- Several habilitation theses: W. Wagner (Karlsruhe 2005), A. Quadt (Bonn 2006), F. Fiedler (Munich 2007), M.-A. Pleier (Bonn 2008), D. Wicke (Wuppertal 2009). and recent scientific publications and reviews.
Module: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises [M-PHYS-104084]

4.149 Module: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises [M-PHYS-104084]

**Responsible:** Prof. Dr. Günter Quast
PD Dr. Klaus Rabbertz
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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**Mandatory**

| T-PHYS-108470 | Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises | 8 CR | Quast, Rabbertz, Wolf |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104081 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises must not have been started.
2. The module M-PHYS-104082 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-104085 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor) must not have been started.

**Competence Goal**

The students are able to present the theoretical and experimental basics of the physics of massive bosons in the Standard Model, together with the most important related measurements at colliders. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in W/Z/H physics. The students solve problems as a team and improve their presentation skills. ONLY 8 ECTS: The students are able to research and analyse scientific publications in the field of particle physics.

**Content**


**Workload**

240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**

Basic knowledge from the bachelor lectures "Moderne Experimentalphysik III", "Moderne Theoretische Physik II" and "Rechnernutzung in der Physik" as well as from the master lecture "Particle Physics I" is assumed.

**Literature**

- M. Mozer: Electroweak Physics at the LHC, Springer (2016)
- R. Wolf: The Higgs Boson Discovery at the Large Hadron Collider, Springer 2015
4.150 Module: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor)
[M-PHYS-104085]

**Responsible:**
Prof. Dr. Günter Quast
PD Dr. Klaus Rabbertz
PD Dr. Roger Wolf

**Organisation:**
KIT Department of Physics

**Part of:**
Minor in Physics: Experimental Particle Physics

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**Mandatory**
T-PHYS-108471 Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor) 8 CR Quast, Rabbertz, Wolf

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
one

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-104081 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises must not have been started.
2. The module M-PHYS-104082 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) must not have been started.
3. The module M-PHYS-104084 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises must not have been started.

**Competence Goal**
The students are able to present the theoretical and experimental basics of the physics of massive bosons in the Standard Model, together with the most important related measurements at colliders. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in W/Z/H physics. The students solve problems as a team and improve their presentation skills. The students are able to research and analyse scientific publications in the field of particle physics.

**Content**

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

**Recommendation**
Basic knowledge from the bachelor lectures "Moderne Experimentalphysik III", "Moderne Theoretische Physik II" and "Rechnernutzung in der Physik" as well as from the master lecture "Particle Physics I" is assumed.

**Literature**
- M. Mozer: Electroweak Physics at the LHC, Springer (2016)
- R. Wolf: The Higgs Boson Discovery at the Large Hadron Collider, Springer 2015
### Module: Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises [M-PHYS-104081]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz  
PD Dr. Roger Wolf  

**Organisation:** KIT Department of Physics  

**Part of:**  
- Major in Physics: Experimental Particle Physics (Required Elective Experimental Particle Physics)  
- Second Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)

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#### Competence Certificate

**Oral Exam.** In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

#### Prerequisites

none

#### Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-104082 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) must not have been started.
2. The module M-PHYS-104084 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises must not have been started.
3. The module M-PHYS-104085 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor) must not have been started.

#### Competence Goal

The students are able to present the theoretical and experimental basics of the physics of massive bosons in the Standard Model, together with the most important related measurements at colliders. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in W/Z/H physics. The students solve problems as a team and improve their presentation skills.

#### Content


#### Workload

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

#### Recommendation

Basic knowledge from the bachelor lectures "Moderne Experimentalphysik III", "Moderne Theoretische Physik II" and "Rechnernutzung in der Physik" as well as from the master lecture "Particle Physics I" is assumed.

#### Literature

- M. Mozer: Electroweak Physics at the LHC, Springer (2016)
- R. Wolf: The Higgs Boson Discovery at the Large Hadron Collider, Springer 2015
Module: Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) [M-PHYS-104082]

**4.152 Module: Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) [M-PHYS-104082]**

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Experimental Particle Physics

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**Mandatory**

| T-PHYS-108469 | Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) | 6 CR | Quast, Rabbertz, Wolf |

**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module **M-PHYS-104081 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises** must not have been started.
2. The module **M-PHYS-104084 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises** must not have been started.
3. The module **M-PHYS-104085 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor)** must not have been started.

**Competence Goal**  
The students are able to present the theoretical and experimental basics of the physics of massive bosons in the Standard Model, together with the most important related measurements at colliders. Thus, they extend their knowledge in a specific field of experimental particle physics, and they are familiar with the current state of research. The students understand modern, computer-based techniques of data analysis and are able to apply them to simple problems in W/Z/H physics. The students solve problems as a team and improve their presentation skills.

**Content**  

**Workload**  
180 hours consisting of attendance time (45 hours), wrap-up of lecture and preparation of exercises (135 hours).

**Recommendation**  
Basic knowledge from the bachelor lectures "Moderne Experimentalphysik III", "Moderne Theoretische Physik II" and "Rechnernutzung in der Physik" as well as from the master lecture "Teilchenphysik I" is assumed.

**Literature**

- M. Mozer: Electroweak Physics at the LHC, Springer (2016)
- R. Wolf: The Higgs Boson Discovery at the Large Hadron Collider, Springer 2015
**4.153 Module: Particle Physics with Extra Dimensions [M-PHYS-106055]**

**Responsible:** Dr. Monika Blanke  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
- Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-112244 | Particle Physics with Extra Dimensions | 4 CR | Blanke, Nierste |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

Knowledge of quantum field theory and the standard model of particle physics is required.

**Competence Goal**

The students are able to study and understand concepts of modern particle physics, in particular related to extensions of the Standard Model with extra space-time dimensions.

**Content**

This module introduces theoretical concepts of particle physics with extra space-time dimensions and discusses their phenomenology. Topics include:

- compactification, orbifolds and boundary conditions
- 5D fields and Kaluza-Klein decomposition
- gauge-Higgs unification
- warped geometry and the Randall-Sundrum model
- gauge and flavour hierarchies in RS
- AdS/CFT correspondence

**Workload**

120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours).

**Literature**

Will be announced in the first lecture
4.154 Module: Photovoltaics [M-ETIT-100513]

**Responsible:** Prof. Dr.-Ing. Michael Powalla

**Organisation:** KIT Department of Electrical Engineering and Information Technology

**Part of:** Major in Physics: Optics and Photonics (Elective Optics and Photonics)  
Second Major in Physics: Optics and Photonics

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**Mandatory**

| T-ETIT-101939 | Photovoltaics | 6 CR | Powalla |

**Prerequisites**

Module "M-ETIT-100524 - Solar Energy" must not have started.
Module: Physics of Seismic Instruments [M-PHYS-102358]

**Responsible:** Dr. Thomas Forbriger

**Organisation:** KIT Department of Physics

**Part of:** Second Major in Physics: Geophysics

**Credits:** 6

**Grading scale:** Grade to a tenth

**Recurrence:** Each winter term

**Duration:** 1 term

**Language:** English

**Level:** 4

**Version:** 2

**Mandatory**

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**Competence Certificate**

To pass the module, an oral exam must be passed (approx. 20 minutes). As prerequisite a student must successfully participate in the corresponding exercise classes. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and written tests held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Illias.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102653 - Physics of Seismic Instruments (Minor) must not have been started.

**Competence Goal**

The students understand the causes and consequences of different physical excitation mechanisms for inertial seismometers. They can explain essential considerations for installation and shielding. The students understand the concept of frequency response and are able to express a transfer function in terms of poles and zeroes. They can apply these concepts to sensors with electrodynamic transducers. The students can explain the significance of linearity. They are able to quantitatively infer the physical input signal from the recording of a seismic instrument. The students are able to use the concepts of bandwidth and dynamic range when expressing properties of signals and instruments. The students know means to express noise levels and to estimate instrumental self-noise. They can explain measures to increase the sensitivity and can explain the essential principles of modern force-balance feedback seismometers.

**Content**

- The mechanical sensor and the driven harmonic oscillator
- Various driving forces and wanted and unwanted sensitivity
- Installation and shielding
- The seismometer with electrodynamic transducer, effective gain, and damping due to passive electrodynamic feedback
- The frequency response, transfer function, poles and zeroes, non-linearity
- Seismic signals, bandwidth, dynamic range, and noise floor
- The force-balance feedback seismometer, displacement transducer, phase sensitive rectifier, controller, and the role of open-loop gain
- Effective transfer function of the velocity broad-band seismometer

**Workload**

180 hours composed of attendance time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**

A sound knowledge of the theory of ordinary differential equations and integral transformations (Fourier transformation) is expected. Basic skills in practical signal processing using elementary computer programming techniques are needed in the exercises. A basic understanding of seismic waves in the Earth is helpful.
Literature


Further recommendations will be given during the course.
4.156 Module: Physics of Seismic Instruments (Minor) [M-PHYS-102653]

**Responsible:** Dr. Thomas Forbriger  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Geophysics

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**Competence Certificate**

To pass the module, a student must successfully participate the corresponding exercise classes. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and written tests held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Ilias.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102358 - Physics of Seismic Instruments must not have been started.

**Competence Goal**

The students understand the causes and consequences of different physical excitation mechanisms for inertial seismometers. They can explain essential considerations for installation and shielding. The students understand the concept of frequency response and are able to express a transfer function in terms of poles and zeroes. They can apply these concepts to sensors with electrodynamic transducers. The students can explain the significance of linearity. They are able to quantitatively infer the physical input signal from the recording of a seismic instrument. The students are able to use the concepts of bandwidth and dynamic range when expressing properties of signals and instruments. The students know means to express noise levels and to estimate instrumental self-noise. They can explain measures to increase the sensitivity and can explain the essential principles of modern force-balance feedback seismometers.

**Content**

- The mechanical sensor and the driven harmonic oscillator
- Various driving forces and wanted and unwanted sensitivity
- Installation and shielding
- The seismometer with electrodynamic transducer, effective gain, and damping due to passive electrodynamic feedback
- The frequency response, transfer function, poles and zeroes, non-linearity
- Seismic signals, bandwidth, dynamic range, and noise floor
- The force-balance feedback seismometer, displacement transducer, phase sensitive rectifier, controller, and the role of open-loop gain
- Effective transfer function of the velocity broad-band seismometer

**Workload**

180 hours composed of attendance time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**

A sound knowledge of the theory of ordinary differential equations and integral transformations (Fourier transformation) is expected. Basic skills in practical signal processing using elementary computer programming techniques are needed in the exercises. A basic understanding of seismic waves in the Earth is helpful.
Literature


Further recommendations will be given during the course.
4.157 Module: Physics of Semiconductors, with Exercises [M-PHYS-102131]

**Responsible:** Prof. Dr. Heinz Kalt

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Required Condensed Matter)
- Major in Physics: Nanophysics (Required Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Mandatory**

| T-PHYS-102343 | Physics of Semiconductors, with Exercises | 10 CR | Kalt |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102130 - Physics of Semiconductors, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102301 - Physics of Semiconductors, without Exercises must not have been started.

**Competence Goal**

The students

- know characteristic details of the semiconductor band structure and can justify them theoretically
- know the description of equilibrium and non-equilibrium processes and are able to calculate typical phenomena in semiconductors
- can explain and calculate transport phenomena and dynamic problems with the help of differential equations of internal electronics
- understand the importance of temporal or spatial inhomogeneity as a driving force for these processes
- understand the band characteristics and physical properties of semiconductor transitions
- can describe and theoretically justify the phenomenological behavior and typical applications of semiconductor devices on the basis of the fundamentals they have learned
- can calculate the behavior of devices themselves using selected examples

**Content**

1. Basic properties of semiconductors (material classes, band structure, k*p theory, statistics, Boltzmann equilibrium).
2. Non-equilibrium processes in semiconductors (Boltzmann equation, generation and recombination, transport phenomena)
3. Semiconductor junctions in thermodynamic equilibrium (pn junction, heterojunctions, low-dimensional semiconductors, Schottky contact, ohmic contact, insulator-semiconductor transition)
4. Semiconductor junctions in non-equilibrium / devices (diode, photodiode, solar cell, LED, diode laser, microwave devices, bipolar transistor, field effect transistor, CCD, memory devices, ...)
5. Semiconductor technology (epitaxy, doping, structuring, integration)

**Workload**

300 hours consisting of attendance time (75 hrs.), wrap-up of the lecture, processing of the exercises as well as exam preparation (225 hrs.)

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.
Literature
R. Enderlein, N. Horing: Fundamentals of Semiconductor Physics and Devices
M. Grundmann: The Physics of Semiconductors
S.M. Sze, K.K. Ng: Physics of Semiconductor Devices
Module: Physics of Semiconductors, with Exercises (Minor) [M-PHYS-102130]

**Responsible:** Prof. Dr. Heinz Kalt

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Nanophysics

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**Mandatory**

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<td>Physics of Semiconductors, with Exercises (Minor)</td>
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**Competence Certificate**

Proof of this module as a minor subject in physics requires successful participation in the exercises. This is certified as an ungraded course achievement.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102131 - Physics of Semiconductors, with Exercises must not have been started.
2. The module M-PHYS-102301 - Physics of Semiconductors, without Exercises must not have been started.

**Competence Goal**

The students

- know characteristic details of the semiconductor band structure and can justify them theoretically
- know the description of equilibrium and non-equilibrium processes and are able to calculate typical phenomena in semiconductors
- can explain and calculate transport phenomena and dynamic problems with the help of differential equations of internal electronics
- understand the importance of temporal or spatial inhomogeneity as a driving force for these processes
- understand the band characteristics and physical properties of semiconductor transitions
- can describe and theoretically justify the phenomenological behavior and typical applications of semiconductor devices on the basis of the fundamentals they have learned
- can calculate the behavior of devices themselves using selected examples

**Content**

1. Basic properties of semiconductors (material classes, band structure, k*p theory, statistics, Boltzmann equilibrium).
2. Non-equilibrium processes in semiconductors (Boltzmann equation, generation and recombination, transport phenomena).
3. Semiconductor junctions in thermodynamic equilibrium (pn junction, heterojunctions, low-dimensional semiconductors, Schottky contact, ohmic contact, insulator-semiconductor transition).
4. Semiconductor junctions in non-equilibrium/ devices (diode, photodiode, solar cell, LED, diode laser, microwave devices, bipolar transistor, field effect transistor, CCD, memory devices, ...)
5. Semiconductor technology (epitaxy, doping, structuring, integration)

**Workload**

300 hours consisting of attendance time (75 hrs.), wrap-up of lecture, completion of exercises (225 hrs.)

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

R. Enderlein, N. Horing: *Fundamentals of Semiconductor Physics and Devices*

M. Grundmann: *The Physics of Semiconductors*

S.M. Sze, K.K. Ng: *Physics of Semiconductor Devices*
Module: Physics of Semiconductors, without Exercises [M-PHYS-102301]

### Responsible
Prof. Dr. Heinz Kalt

### Organisation
KIT Department of Physics

### Credits
8

### Grade scale
Grade to a tenth

### Recurrence
Each summer term

### Duration
1 term

### Language
German

### Level
4

### Version
1

### Mandatory

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### Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

### Prerequisites
none

### Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102130 - Physics of Semiconductors, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102131 - Physics of Semiconductors, with Exercises must not have been started.

### Competence Goal
The students

- know characteristic details of the semiconductor band structure and can justify them theoretically
- know the description of equilibrium and non-equilibrium processes
- can explain transport phenomena and dynamic problems with the help of the differential equations of internal electronics
- understand the importance of temporal or spatial inhomogeneity as a driving force for these processes
- understand the band characteristics and physical properties of semiconductor transitions
- can describe and theoretically justify the phenomenological behavior and typical applications of semiconductor devices on the basis of the fundamentals learned

### Content

1. Basic properties of semiconductors (material classes, band structure, k*p theory, statistics, Boltzmann equilibrium).
2. Non-equilibrium processes in semiconductors (Boltzmann equation, generation and recombination, transport phenomena)
3. Semiconductor junctions in thermodynamic equilibrium (pn junction, heterojunctions, low-dimensional semiconductors, Schottky contact, ohmic contact, insulator-semiconductor transition)
4. Semiconductor junctions in non-equilibrium/ devices (diode, photodiode, solar cell, LED, diode laser, microwave devices, bipolar transistor, field effect transistor, CCD, memory devices, ...)
5. Semiconductor technology (epitaxy, doping, structuring, integration)

### Workload
240 hours consisting of attendance time (60 hrs.), wrap-up of the lecture as well as exam preparation (180 hrs.)

### Recommendation
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

### Literature
R. Enderlein, N. Horing: Fundamentals of Semiconductor Physics and Devices
M. Grundmann: The Physics of Semiconductors
S.M. Sze, K.K. Ng: Physics of Semiconductor Devices
4.160 Module: Precision Phenomenology at Colliders and Computational Methods, with Exercises [M-PHYS-105640]

Responsible: Prof. Dr. Gudrun Heinrich

Organisation: KIT Department of Physics

Part of: Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
Second Major in Physics: Theoretical Particle Physics

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Mandatory

T-PHYS-111279 Precision Phenomenology at Colliders and Computational Methods, with Exercises 8 CR Heinrich

Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-105641 - Precision Phenomenology at Colliders and Computational Methods, without Exercises must not have been started.
2. The module M-PHYS-105642 - Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor) must not have been started.

Competence Goal

The course provides knowledge about perturbative Quantum Chromodynamics (QCD) and its infrared structure, as well as on current topics in particle physics phenomenology, i.e. the comparison of measurements at colliders like the CERN Large Hadron Collider to theoretical predictions. Concepts and tools to calculate simple processes at at next-to-leading order in perturbation theory are acquired and computer programs that are used in the field of precision calculations are presented. The knowledge is deepened by the accompanying exercises.

Content

This Module gives an overview on current techniques and topics in collider physics from a theoretical physics point of view. Topics are QCD, colour algebra, factorisation, jets and event shapes, top-quark and Higgs physics. The treatment of infrared divergences in QCD is discussed, as well as parton evolution and parton densities. Methods and tools to perform calculations beyond the leading order in perturbation theory are introduced.

Workload

240 hours consisting of attendance time (60 h), follow-up of the lecture incl. exam preparation and preparation and follow-up of the exercises (180 h).

Recommendation

Knowledge on the level of TTP0 or TTP>0 is an advantage

Literature

- Dissertori, Knowles, Schmelling, "Quantum Chromodynamics: High energy experiments and theory", Oxford University Press;
Module: Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor) [M-PHYS-105642]

### Responsible
Prof. Dr. Gudrun Heinrich

### Organisation
KIT Department of Physics

### Part of
Minor in Physics: Theoretical Particle Physics

### Credits
8

### Grading scale
pass/fail

### Recurrence
Irregular

### Duration
1 term

### Language
English

### Level
4

### Version
1

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#### Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

#### Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-105640 - Precision Phenomenology at Colliders and Computational Methods, with Exercises must not have been started.
2. The module M-PHYS-105641 - Precision Phenomenology at Colliders and Computational Methods, without Exercises must not have been started.

#### Competence Goal
The course provides knowledge about perturbative Quantum Chromodynamics (QCD) and its infrared structure, as well as on current topics in particle physics phenomenology, i.e. the comparison of measurements at colliders like the CERN Large Hadron Collider to theoretical predictions. Concepts and tools to calculate simple processes at next-to-leading order in perturbation theory are acquired and computer programs that are used in the field of precision calculations are presented. The knowledge is deepened by the accompanying exercises.

#### Content
This Module gives an overview on current techniques and topics in collider physics from a theoretical physics point of view. Topics are QCD, colour algebra, factorisation, jets and event shapes, top-quark and Higgs physics. The treatment of infrared divergences in QCD is discussed, as well as parton evolution and parton densities. Methods and tools to perform calculations beyond the leading order in perturbation theory are introduced.

#### Workload
240 hours consisting of attendance time (60 h), follow-up of the lecture and preparation and follow-up of the exercises (180 h).

#### Recommendation
Knowledge on the level of TTP0 or TTP>0 is an advantage

#### Literature
- Dissertori, Knowles, Schmelling, "Quantum Chromodynamics: High energy experiments and theory", Oxford University Press;
4.162 Module: Precision Phenomenology at Colliders and Computational Methods, without Exercises [M-PHYS-105641]

**Responsible:** Prof. Dr. Gudrun Heinrich

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
- Second Major in Physics: Theoretical Particle Physics

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105640 - Precision Phenomenology at Colliders and Computational Methods, with Exercises must not have been started.
2. The module M-PHYS-105642 - Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor) must not have been started.

**Competence Goal**

The course provides knowledge about perturbative Quantum Chromodynamics (QCD) and its infrared structure, as well as on current topics in particle physics phenomenology, i.e. the comparison of measurements at colliders like the CERN Large Hadron Collider to theoretical predictions. Concepts and tools to calculate simple processes at next-to-leading order in perturbation theory are acquired and computer programs that are used in the field of precision calculations are presented.

**Content**

This Module gives an overview on current techniques and topics in collider physics from a theoretical physics point of view. Topics are QCD, colour algebra, factorisation, jets and event shapes, top-quark and Higgs physics. The treatment of infrared divergences in QCD is discussed, as well as parton evolution and parton densities. Methods and tools to perform calculations beyond the leading order in perturbation theory are introduced. For this variant without the exercises there will be less details on the computational aspects.

**Workload**

120 hours consisting of attendance time (30 h), wrap-up of lecture incl. exam preparation (90 h).

**Recommendation**

Knowledge on the level of TTP0 or TTP>0 is an advantage

**Literature**

- Dissertori, Knowles, Schmelling, "Quantum Chromodynamics: High energy experiments and theory", Oxford University Press;
4.163 Module: Quantum Detectors and Sensors [M-PHYS-106193]

**Responsible:** Prof. Dr. Sebastian Kempf  
**Organisation:** KIT Department of Electrical Engineering and Information Technology  
**Part of:** Major in Physics: Experimental Particle Physics (Elective Experimental Particle Physics)  
**Second Major in Physics: Experimental Astroparticle Physics (Elective Experimental Astroparticle Physics)**

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**Mandatory**

| T-PHYS-112582 | Quantum Detectors and Sensors | 8 CR | Kempf |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Competence Goal**

Students know the basics and fundamentals of quantum detectors and sensors and understand how quantum technology can be used to design and realize devices whose performance reaches far beyond the limits of any classical sensor or detector. They know the basic components of quantum sensors and detectors, in particular in the field of superconducting quantum technology, and are able to analyze the operation of such detectors and sensors on the basis of circuit diagrams. Students are able to develop quantum sensors and detectors for given applications and know how to consider special requirements in a concrete component.

**Content**

This module provides a comprehensive overview of the basics and physical principles of quantum detectors and sensors and discusses in detail how quantum technology can be used to design and realize detectors and sensors with performance that reaches far beyond the limits of any classical sensor or detector. The discussion includes particularly an introduction to the basic components of quantum sensors and detectors, especially in the field of superconducting quantum technology, and their fabrication. Using simplified circuit diagrams, the functionality and operation of quantum detectors and sensors such as superconducting quantum interference devices, low-temperature detectors, noise thermometers or superconducting radiation detectors is analyzed. Furthermore, methods and simple models are developed allowing to realize quantum sensors and detectors that are matched to given applications. Within this context, typical applications of quantum detectors and sensors are also discussed.

The tutorial is closely related to the lecture and deals with special aspects concerning the development of quantum detectors and sensors. In particular, the development and system integration of quantum detectors and sensors for applications in precision metrology, particle detection or applied sciences is discussed by means of exercises.

**Annotation**

The lecture and exercise will be offered in English. However, questions and discussions can of course also be held in German.

**Workload**

240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and working on the exercises (180 hours)

**Literature**

Will be announced in the lecture.
4.164 Module: Quantum Detectors and Sensors (Minor) [M-PHYS-106194]

**Responsible:** Prof. Dr. Sebastian Kempf

**Organisation:** KIT Department of Electrical Engineering and Information Technology

**Part of:** Minor in Physics: Experimental Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the written exam by reaching at least 50% of the total points.

**Prerequisites**
none

**Competence Goal**
Students know the basics and fundamentals of quantum detectors and sensors and understand how quantum technology can be used to design and realize devices those performance reaches far beyond the limits of any classical sensor or detector. They know the basic components of quantum sensors and detectors, in particular in the field of superconducting quantum technology, and are able to analyze the operation of such detectors and sensors on the basis of circuit diagrams. Students are able to develop quantum sensors and detectors for given applications and know how to consider special requirements in a concrete component.

**Content**
This module provides a comprehensive overview of the basics and physical principles of quantum detectors and sensors and discusses in detail how quantum technology can be used to design and realize detectors and sensors with performance that reaches far beyond the limits of any classical sensor or detector. The discussion includes particularly an introduction to the basic components of quantum sensors and detectors, especially in the field of superconducting quantum technology, and their fabrication. Using simplified circuit diagrams, the functionality and operation of quantum detectors and sensors such as superconducting quantum interference devices, low-temperature detectors, noise thermometers or superconducting radiation detectors is analyzed. Furthermore, methods and simple models are developed allowing to realize quantum sensors and detectors that are matched to given applications. Within this context, typical applications of quantum detectors and sensors are also discussed.

The tutorial is closely related to the lecture and deals with special aspects concerning the development of quantum detectors and sensors. In particular, the development and system integration of quantum detectors and sensors for applications in precision metrology, particle detection or applied sciences is discussed by means of exercises.

**Annotation**
The lecture and exercise will be offered in English. However, questions and discussions can of course also be held in German.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises incl. exam preparation (180 hours).

**Literature**
Will be announced in the lecture.
Module: Quantum Optics at the Nano Scale, with Exercises [M-PHYS-106508]

Responsible: Prof. Dr. David Hunger
Organisation: KIT Department of Physics
Part of:
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics

Credits 8
Grading scale Grade to a tenth
Recurrence Irregular
Duration 1 term
Language English
Level 4
Version 1

Mandatory

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Competence Certificate

Oral. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites

none

Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-106509 - Quantum Optics at the Nano Scale, with Exercises (Minor) must not have been started.
2. The module M-PHYS-106510 - Quantum Optics at the Nano Scale, without Exercises must not have been started.

Competence Goal

Students gain knowledge about the fundamentals in the field of quantum- and nano optics and learn about basic concepts and examples of optical quantum systems. This is intended to enable participants to follow current research in the field. The Tutorial is designed as a journal club, where selected publications will be presented by students. Students learn how to become familiar with current research topics, how to interpret research results based on the concepts presented in the lecture, and how to present scientific results.

Content

- Fundamentals of quantized light fields and light-matter interactions
- Micro- and nanooptical devices
- Dipole emission in structured environments
- Solid state quantum emitters
- Optical readout of single spins
- Quantum communication
- Quantum networks
- Quantum sensing
- Quantum computing

Workload

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

Recommendation

Basic knowledge in classical electromagnetism and optics, quantum mechanics, atomic physics; quantum optics is beneficial but not mandatory

Literature

- Principles of Nano-Optics, Novotny, Hecht, Cambridge University Press
- Fundamentals of Photonics, Saleh,Teich
- research articles (will be sent around)
Module: Quantum Optics at the Nano Scale, with Exercises (Minor) [M-PHYS-106509]

Responsible: Prof. Dr. David Hunger
Organisation: KIT Department of Physics
Part of: Minor in Physics: Nanophysics
Minor in Physics: Optics and Photonics

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Mandatory
T-PHYS-113127 Quantum Optics at the Nano Scale, with Exercises (Minor) 8 CR Hunger

Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-106508 - Quantum Optics at the Nano Scale, with Exercises must not have been started.
2. The module M-PHYS-106510 - Quantum Optics at the Nano Scale, without Exercises must not have been started.

Competence Goal
Students gain knowledge about the fundamentals in the field of quantum- and nano optics and learn about basic concepts and examples of optical quantum systems. This is intended to enable participants to follow current research in the field. The Tutorial is designed as a journal club, where selected publications will be presented by students. Students learn how to become familiar with current research topics, how to interpret research results based on the concepts presented in the lecture, and how to present scientific results.

Content
- Fundamentals of quantized light fields and light-matter interactions
- Micro- and nano-optical devices
- Dipole emission in structured environments
- Solid state quantum emitters
- Optical readout of single spins
- Quantum communication
- Quantum networks
- Quantum sensing
- Quantum computing

Workload
240 hours consisting of attendance time (60 hours), wrap-up of lecture and preparation of exercises (180 hours).

Recommendation
Basic knowledge in classical electromagnetism and optics, quantum mechanics, atomic physics; quantum optics is beneficial but not mandatory

Literature
- Principles of Nano-Optics, Novotny, Hecht, Cambridge University Press
- Fundamentals of Photonics, Saleh, Teich
- research articles (will be sent around)
## 4.167 Module: Quantum Optics at the Nano Scale, without Exercises [M-PHYS-106510]

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<th>Prof. Dr. David Hunger</th>
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### Mandatory

| T-PHYS-113128 | Quantum Optics at the Nano Scale, without Exercises | 6 CR | Hunger |

### Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

### Prerequisites

none

### Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-106508 - Quantum Optics at the Nano Scale, with Exercises must not have been started.
2. The module M-PHYS-106509 - Quantum Optics at the Nano Scale, with Exercises (Minor) must not have been started.

### Competence Goal

Students gain knowledge about the fundamentals in the field of quantum- and nano optics and learn about basic concepts and examples of optical quantum systems. This is intended to enable participants to follow current research in the field.

### Content

- Fundamentals of quantized light fields and light-matter interactions
- Micro- and nano-optical devices
- Dipole emission in structured environments
- Solid state quantum emitters
- Optical readout of single spins
- Quantum communication
- Quantum networks
- Quantum sensing
- Quantum computing

### Workload

180 hours consisting of attendance time (45 hours), wrap-up of lecture incl. exam preparation (135 hours).

### Recommendation

Basic knowledge in classical electromagnetism and optics, quantum mechanics, atomic physics; quantum optics is beneficial but not mandatory

### Literature

- Principles of Nano-Optics, Novotny, Hecht, Cambridge University Press
- Fundamentals of Photonics, Saleh,Teich
- research articles (will be sent around)
Module: Seismic Data Processing with Final Report (Graded) [M-PHYS-104186]

**Responsible:** Prof. Dr. Thomas Bohlen  
Dr. Thomas Hertweck  

**Organisation:** KIT Department of Physics  

**Part of:** Second Major in Physics: Geophysics  

<table>
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**Mandatory**

- T-PHYS-108656 Seismic Data Processing, Final Report (Graded) 4 CR Bohlen, Hertweck  
- T-PHYS-108686 Seismic Data Processing, Coursework 2 CR Bohlen, Hertweck  

**Competence Certificate**
Students have to participate the lecture/exercise on a regular basis and give a final presentation about their processing results (2 ECTS points). Students who would like to get the full 6 ECTS points also need to prepare and hand in a seismic data processing report. The report will determine the final grade (if applicable).

**Prerequisites**
None  

**Competence Goal**
The students have hands-on experience applying typical seismic processing and imaging techniques to reflection seismic field data. In this way, they understand the reflection seismic method and have practical skills in data analysis and problem solving which are beneficial in their professional life later on, not only in exploration. Students can set up a basic processing and imaging flow, understand the individual processing steps and their purpose, and describe the influence of important parameters on processing results. They are able to identify data shortcomings and imaging challenges and develop basic solutions, analyze the success of individual processing/imaging steps, and critically assess the overall quality of their work. Finally, students are able to present their processing results in oral and written form.

**Content**
- Field data loading, quality control, trace edits and geometry setup
- Spectral analysis, filter application, geometrical spreading correction
- Deconvolution, zero-phasing
- Denoising using various approaches
- Multiple identification and removal (SRME, Radon)
- CMP sort, velocity analysis, NMO correction, mute and stack
- Time migration (prestack and poststack)
- Post-migration processing
- Basic interpretation (in cooperation with KIT-AGW)
- Optional: depth velocity model building and depth migration

**Module grade calculation**
The report will determine the final grade.

**Annotation**
A commercial data processing software is used during this course.

**Workload**
180 h hours composed of contact time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**
No explicit requirements. However, basic knowledge of the reflection seismic method and general computer skills are essential. This course does not require any programming skills.

**Learning type**
4060321 Th.Bohlen, Th. Hertweck (V1)  
4060322 Th.Bohlen, Th. Hertweck (Ü2)
Literature

4.169 Module: Seismic Modeling [M-PHYS-105227]

**Responsible:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** Second Major in Physics: Geophysics

<table>
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**Mandatory**

| T-PHYS-110605 | Seismic Modeling | 4 CR | Bohlen |

**Competence Certificate**

To pass the module, the oral exam (approx. 20 minutes) must be passed. As prerequisites the examinations of other type must be passed, based on successful participation of the exercises. Each exercise deals with a specific topic (e.g., 1D finite-difference implementation) and is based on hands-on work, usually involving the use of computers.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105228 - Seismic Modeling (Minor) must not have been started.

**Competence Goal**

The students know the fundamental concepts of seismic wavefield simulations, including the mathematical descriptions and their basic numeric implementations. They understand the complexity of wave propagation and the advantages and disadvantages of the individual methods. They are able to apply the methods using synthetic Earth models to calculate amplitudes and travel times of propagating elastic and/or acoustic waves.

**Content**

- Factors influencing travel times and amplitudes of seismic wavefields
- Analytical solutions
- Fast traveltime calculation using the eikonal equation
- Ray tracing
- Reflectivity method for acoustic 1D media
- Time-domain finite-difference solutions of the acoustic/elastic wave equations
- Fourier methods
- Introduction to the finite-element method

**Module grade calculation**

The grade of the module results from grade of the oral exam.

**Recommendation**

Knowledge of differential and vector calculus is essential. Familiarity with Matlab (alternatively Python or Mathematica) is beneficial for certain exercises.

**Learning type**

V1 Ü1, 2 SWS, 4 ECTS

**Literature**

4.170 Module: Seismic Modeling (Minor) [M-PHYS-105228]

**Responsible:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Geophysics

<table>
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**Mandatory**

| T-PHYS–110607 | Seismic Modeling (Minor) | 4 CR | Bohlen |

**Competence Certificate**

To pass the module, the examinations of other type must be passed, based on successful participation of the exercises. Each exercise deals with a specific topic (e.g., 1D finite-difference implementation) and is based on hands-on work, usually involving the use of computers.

**Prerequisites**

None

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-105227 - Seismic Modeling** must not have been started.

**Competence Goal**

The students know the fundamental concepts of seismic wavefield simulations, including the mathematical descriptions and their basic numeric implementations. They understand the complexity of wave propagation and the advantages and disadvantages of the individual methods. They are able to apply the methods using synthetic Earth models to calculate amplitudes and traveltimes of propagating elastic and/or acoustic waves.

**Content**

- Factors influencing traveltimes and amplitudes of seismic wavefields
- Analytical solutions
- Fast traveltime calculation using the eikonal equation
- Raytracing
- Reflectivity method for acoustic 1D media
- Time-domain finite-difference solutions of the acoustic/elastic wave equations
- Fourier methods
- Introduction to the finite-element method

**Recommendation**

Knowledge of differential and vector calculus is essential. Familiarity with Matlab (alternatively Python or Mathematica) is beneficial for certain exercises.

**Learning type**

V1 Ü1, 2 SWS, 4 ECTS

**Literature**

Competence Certificate
To pass the module, an oral exam must be passed (approx. 20 min). As prerequisite a student must successfully participate the corresponding exercise classes. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and written tests held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Ilias.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-106325 - Seismics (Minor) must not have been started.

Competence Goal
The students know the fundamental concepts of seismic acquisition, processing and imaging in reflection seismics. They can correctly name equipment, tools and processes and effectively communicate with specialists in the field of seismics. Students understand the various steps involved in seismic processing/imaging, their underlying theory and how they affect the data. They are able to apply the concepts and equations to simple exemplary seismic data.

Content
- Overview of seismic methods and wave propagation basics
- Essential signal processing concepts and tools
- Seismic acquisition, sources and receivers, marine and land
- Geometries and traveltimes, NMO and DMO
- Processing steps: from data loading to denoise and demultiple
- Velocity analysis, NMO correction, stacking, SNR
- Imaging: basic concepts, time and depth migration, migration methods
- Seismic resolution
- Optional: advanced acquisition, processing and imaging technologies

Workload
240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

Recommendation
Experience with Matlab, the Linux commandline, and shell scripts is beneficial. Knowledge of fundamental signal processing theory is essential.

Literature
Module: Seismics (Minor) [M-PHYS-106325]

**Responsibility:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Geophysics

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**Competence Certificate**
To pass the module, a student must successfully participate in the corresponding exercise classes. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and written tests held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Ilias.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-106326 - Seismics must not have been started.

**Competence Goal**
The students know the fundamental concepts of seismic acquisition, processing and imaging in reflection seismics. They can correctly name equipment, tools and processes and effectively communicate with specialists in the field of seismics. Students understand the various steps involved in seismic processing/imaging, their underlying theory and how they affect the data. They are able to apply the concepts and equations to simple exemplary seismic data.

**Content**

- Overview of seismic methods and wave propagation basics
- Essential signal processing concepts and tools
- Seismic acquisition, sources and receivers, marine and land
- Geometries and traveltimes, NMO and DMO
- Processing steps: from data loading to denoise and demultiple
- Velocity analysis, NMO correction, stacking, SNR
- Imaging: basic concepts, time and depth migration, migration methods
- Seismic resolution
- Optional: advanced acquisition, processing and imaging technologies

**Workload**
240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

**Recommendation**
Experience with Python/Matlab, the Linux commandline, and shell scripts is beneficial. Knowledge of fundamental signal processing theory is essential.

**Literature**

4.173 Module: Seismology [M-PHYS-105225]

**Responsible:** Prof. Dr. Andreas Rietbrock  
**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Geophysics

**Credits**: 8  
**Grading scale**: Grade to a tenth  
**Recurrence**: Each winter term  
**Duration**: 1 term  
**Language**: English  
**Level**: 4  
**Version**: 2

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**Competence Certificate**
To pass the module, an oral exam must be passed (approx. 20 min). As prerequisites the examinations of other type must be passed, based on successful participation of the exercises. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and presentations based on research papers held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Ilias.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-105226 - Seismology (Minor) must not have been started.

**Competence Goal**
The students understand the fundamental concepts of seismology and the earthquake rupture process. They have a knowledge of seismogram interpretation, fundamentals of seismic wave propagation and the representations of the earthquake source. Students are able to apply their knowledge to observed data to gain an insight into the Earth structure and the earthquake source.

**Content**
- History of seismology
- Elasticity and seismic waves
- Body waves and surface waves
- Seismogram interpretation
- Earthquake location
- Determination of Earth structure
- Seismic sources
- Seismic moment tensor
- Earthquake kinematics and dynamics
- Seismotectonics

**Module grade calculation**
The grade of the module results from grade of the oral exam.

**Workload**
240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

**Recommendation**
A sound knowledge of the fundamentals in Geophysics. Basic skills in programming and Python to solve exercises.

**Literature**
- Peter M. Shearer, "Introduction to Seismology", Cambridge Uniersity Press.
Module: Seismology (Minor) [M-PHYS-105226]

**Responsible:** Prof. Dr. Andreas Rietbrock

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Geophysics

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### Competence Certificate

In order to pass the course Seismology, a student must successfully participate in the corresponding exercise classes. Successful participation is based on exceeding a certain percentage of the combined total number of points awarded, as applicable, for exercise sheets, other homework (such as, for instance, reports) and presentations based on research papers held as part of the exercises. The percentage threshold is communicated to students at the beginning of the course and documented in Ilias.

### Prerequisites

none

### Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-105225 - Seismology must not have been started.

### Competence Goal

The students understand the fundamental concepts of seismology and the earthquake rupture process. They have a knowledge of seismogram interpretation, fundamentals of seismic wave propagation and the representations of the earthquake source. Students are able to apply their knowledge to observed data to gain an insight into the Earth structure and the earthquake source.

### Content

- History of seismology
- Elasticity and seismic waves
- Body waves and surface waves
- Seismogram interpretation
- Earthquake location
- Determination of Earth structure
- Seismic sources
- Seismic moment tensor
- Earthquake kinematics and dynamics
- Seismotectonics

### Workload

240 hours composed of attendance time (60 h), wrap-up of the lectures and solving the exercises (180 h)

### Recommendation

A sound knowledge of the fundamentals in Geophysics. Basic skills in programming and Python to solve exercises.

### Literature

- Peter M. Shearer, "Introduction to Seismology", Cambridge University Press.
4.175 Module: Selected Topics in Meteorology (Minor, ungraded) [M-PHYS-104578]

**Responsible:** Prof. Dr. Corinna Hoose

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Meteorology

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**Elective Subjects (Election: at least 8 credits)**

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<td>Knippertz</td>
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<td>Höpfner, Sinnhuber</td>
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**Competence Certificate**
Coursework can be computer and modelling classes, exercise sheets or preparation of a presentation. Credits will be awarded after passing all courseworks/exercises.

**Prerequisites**
None
Competence Goal
Depending on their choice students can

- explain essential aspects of application aspects of meteorology and assign them to specific application areas. They are capable to describe the functionality of a modern weather forecasting system in detail and can predict the potential for extreme events and their impact on the population and the insurance industry depending on the region and the season. The students are capable of using weather information to derive levels of air pollution and of yields of renewable energy. They can analyse meteorological data using statistical and computer-based methods.

- explain the functionality of modern meteorological measuring methods and measuring principles and name their possible uses. This is especially true for remote sensing, advanced in-situ, trace gas and aerosol measurements. The students can build and execute experiments in the lab or in the field according to instructions, to record and scientifically evaluate data and then interpret and present the results.

- explain essential components of the climate system and their physical properties as well as causes of climate change. Students can know systems for climate monitoring and understand how climate models work. The students can designate essential processes in the atmosphere and ocean, and explain them using physical and chemical laws. They can analyze and interpret climate and weather data based on diagnostic methods. In addition, they can expertly present and discuss learned or self-developed scientific findings.

- name essential processes in the atmosphere and explain these using physical and chemical laws. In particular, students are capable of explaining the structure and dynamics of different cloud systems and of estimating the microphysical processes in clouds or calculating them directly for idealized conditions. In addition, the students are capable of mathematically evaluating the radiation transport in the atmosphere and of describing the importance of radiation processes for the structure of the atmosphere, for climate change and for the measurement of different atmospheric variables. They can also explain the chemical structure and the composition of the aerosols in the troposphere and the stratosphere based on atmospheric physico-chemical processes and transformations. The students can explain the chemical and physical causes of the stratospheric ozone hole and its future development, can describe and classify the main aerosol-cloud processes and are capable of reproducing the main points of the Köhler theory and the classical nucleation theory.

Content
This module aims to give students of other master programs an insight into various areas of meteorology:

- **Applications of meteorology** such as weather forecasting (T-PHYS-109139) and warning (T-PHYS-109140), insurance and energy industry (T-PHYS-109141), data analysis (T-PHYS-109142) and air quality (T-PHYS-108610).

- **Experimental modern measurement methods** in meteorology such as satellite remote sensing (T-PHYS-109133).

- **Components of the climate system** such as the tropics (T-PHYS-107693), the ocean (T-PHYS-108932) and the middle atmosphere (T-PHYS-8931) and their physical and chemical backgrounds as well as modelling their temporal and spatial changes with ICON (T-PHYS-108928) and analysing general climate dynamics and changes (T-PHYS-107692).

- Physical and chemical **processes in the atmosphere** such as cloud physics (T-PHYS-107694), radiation (T-PHYS-107696), aerosols (T-PHYS-8938) and atmospheric energetics (T-PHYS-107695).

- Formation and properties of **planets and their atmospheres** in our solar system applying fundamental principles of physics.

Workload
240 hours composed of active time (45h), wrap-up of the lectures and solving the exercises (195h)

Recommendation
Basic knowledge in Physics, Physical Chemistry and Fluid Dynamics at BSc level
### Module: Selected Topics in Meteorology (Second Major, graded) [M-PHYS-104577]

**Responsible:** Prof. Dr. Corinna Hoose  
**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Meteorology

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**Elective Subjects (Elective: at least 3 items as well as at least 10 credits)**

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<td>Emeis, Ginete Werner Pinto</td>
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<tr>
<td>T-PHYS-111429</td>
<td>Advanced Numerical Weather Prediction</td>
<td>4 CR</td>
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<td>Knippertz</td>
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<tr>
<td>T-PHYS-109177</td>
<td>Physics of Planetary Atmospheres</td>
<td>6 CR</td>
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<td>Leisner</td>
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<tr>
<td>T-PHYS-111273</td>
<td>Arctic Climate System</td>
<td>2 CR</td>
<td></td>
<td>Sinnhuber</td>
</tr>
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</table>

**Competence Certificate**

Coursework can be computer and modelling classes, exercise sheets or preparation of a presentation.

→ successful completion of the prerequisites entitles to exam

**(T-PHYS-109380) Exam on Selected Topics in Meteorology (Second Major):**

Oral exam (approx. 60 minutes) in accordance with § 4 (2) No. 2 SPO Physik Master

**Prerequisites**

None
Competence Goal
Depending on their choice students can

- explain essential aspects of application aspects of meteorology and assign them to specific application areas. They are capable to describe the functionality of a modern weather forecasting system in detail and can predict the potential for extreme events and their impact on the population and the insurance industry depending on the region and the season. The students are capable of using weather information to derive levels of air pollution and of yields of renewable energy. They can analyse meteorological data using statistical and computer-based methods.

- explain the functionality of modern meteorological measuring methods and measuring principles and name their possible uses. This is especially true for remote sensing, advanced in-situ, trace gas and aerosol measurements. The students can build and execute experiments in the lab or in the field according to instructions, to record and scientifically evaluate data and then interpret and present the results.

- explain essential components of the climate system and their physical properties as well as causes of climate change. Students can know systems for climate monitoring and understand how climate models work. The students can designate essential processes in the atmosphere and ocean, and explain them using physical and chemical laws. They can analyze and interpret climate and weather data based on diagnostic methods. In addition, they can expertly present and discuss learned or self-developed scientific findings.

- name essential processes in the atmosphere and explain these using physical and chemical laws. In particular, students are capable of explaining the structure and dynamics of different cloud systems and of estimating the microphysical processes in clouds or calculating them directly for idealized conditions. In addition, the students are capable of mathematically evaluating the radiation transport in the atmosphere and of describing the importance of radiation processes for the structure of the atmosphere, for climate change and for the measurement of different atmospheric variables. They can also explain the chemical structure and the composition of the aerosols in the troposphere and the stratosphere based on atmospheric physico-chemical processes and transformations. The students can explain the chemical and physical causes of the stratospheric ozone hole and its future development, can describe and classify the main aerosol-cloud processes and are capable of reproducing the main points of the Köhler theory and the classical nucleation theory.

Content
This module aims to give students of other master programs an insight into various areas of meteorology:

- Applications of meteorology such as weather forecasting (T-PHYS-109139) and warning (T-PHYS-109140), insurance and energy industry (T-PHYS-109141), data analysis (T-PHYS-109142) and air quality (T-PHYS-108610).

- Experimental modern measurement methods in meteorology such as satellite remote sensing (T-PHYS-109133).

- Components of the climate system such as the tropics (T-PHYS-107693), the ocean (T-PHYS-108932), the arctic (T-PHYS-111273) and the middle atmosphere (T-PHYS-8931) and their physical and chemical backgrounds as well as modelling their temporal and spatial changes with ICON (T-PHYS-108928) and analysing general climate dynamics and changes (T-PHYS-107692).

- Physical and chemical processes in the atmosphere such as cloud physics (T-PHYS-107694), radiation (T-PHYS-107696), aerosols (T-PHYS-8938) and atmospheric energetics (T-PHYS-107695).

- Formation and properties of planets and their atmospheres in our solar system applying fundamental principles of physics.

Module grade calculation
Grade of the Oral Exam.

Workload
420 hours composed of

- active time (79 h),
- wrap-up of the lectures incl. preparation of the oral exam (170 h) and
- solving the exercises (171 h)

Recommendation
Basic knowledge in Physics, Physical Chemistry and Fluid Dynamics at BSc level

**Responsible:** Prof. Dr. Alexey Ustinov  
**Organisation:** KIT Department of Physics  
**Part of:** Major in Physics: Condensed Matter (Elective Condensed Matter)  
Second Major in Physics: Condensed Matter (Elective Condensed Matter)

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**Mandatory**

| T-PHYS-111118 | Solid State Quantum Computing | 4 CR | Ustinov |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

Quantum mechanics 1, Solid state physics (Modern Physics II)

**Competence Goal**

The students will become familiar with the physical foundations of solid-state quantum computing technologies. They will learn about types of quantum circuits based on qubits and resonators, their control, manipulation and measurement techniques. This course is intended to be an introduction into the new interdisciplinary field called quantum engineering.

**Content**

This course has the primary focus on experimental physics and covers the physical foundations of solid-state quantum computing technologies. Solid state quantum computing is a rapidly developing interdisciplinary field involving ideas from quantum mechanics, condensed matter physics, quantum optics, and quantum information processing. In the past few years, quantum computers turned from a dream into reality and offer fascinating opportunities for the future. While classical computers encode the information in bits, quantum computers are built using quantum bits, or qubits. The lecture course will review various types of qubits - quantum hardware that can be or is already used to build quantum computers based on solid-state technologies. We will start from a brief introduction in superconductivity to discuss then the most advanced modern technology based on superconducting quantum circuits. Such circuits with multiple qubits are currently being used in existing quantum computers implemented by Google, IBM, and other IT-companies. Besides superconductors, we will also talk about emerging solid-state quantum platforms such as semiconductor quantum dots, vacancy centers in diamond, solid-state impurity spins and other quantum two-level systems. These emerging versatile approaches are also capable of building primitive single- or two-qubit level circuits. Finally, we will briefly discuss interesting theoretical proposals of condensed matter systems leading to yet unexplored types of qubits, using e.g. electrons on the surface of superfluid helium, impurity spins in fullerenes, and Majorana type qubits.

**Workload**

120 h consisting of attendance time (30 h), wrap-up of lecture incl. exam preparation (90 h)

**Literature**

- A. M. Zagoskin, Quantum Engineering, 2011  
- Quantum Computing: Progress and Prospects, 2019  

**Responsible:** Prof. Dr. Alexey Ustinov

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Condensed Matter (Elective Condensed Matter)
Second Major in Physics: Condensed Matter (Elective Condensed Matter)

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<tr>
<td>8 CR</td>
<td>Solid State Quantum Computing, with Exercises</td>
<td>240 h</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

Quantum mechanics 1, Solid state physics (Modern Physics II)

**Competence Goal**

The students become familiar with the physical foundations of solid-state quantum computing technologies. They learn about types of quantum circuits based on qubits and resonators, their control, manipulation and measurement techniques. Active participation in the exercise class provides the ability to understand and mathematically analyze basic experiments in quantum information processing. This course is intended to be an introduction into the new interdisciplinary field called quantum engineering.

**Content**

This course has the primary focus on experimental physics and covers the physical foundations of solid-state quantum computing technologies. Solid state quantum computing is a rapidly developing interdisciplinary field involving ideas from quantum mechanics, condensed matter physics, quantum optics, and quantum information processing. In the past few years, quantum computers turned from a dream into reality and offer fascinating opportunities for the future. While classical computers encode the information in bits, quantum computers are built using quantum bits, or qubits. The lecture course will review various types of qubits - quantum hardware that can be or is already used to build quantum computers based on solid-state technologies. We will start from a brief introduction in superconductivity to discuss then the most advanced modern technology based on superconducting quantum circuits. Such circuits with multiple qubits are currently being used in existing quantum computers implemented by Google, IBM, and other IT-companies. Besides superconductors, we will also talk about emerging solid-state quantum platforms such as semiconductor quantum dots, vacancy centers in diamond, solid-state impurity spins and other quantum two-level systems. These emerging versatile approaches are also capable of building primitive single- or two-qubit level circuits. Finally, we will briefly discuss interesting theoretical proposals of condensed matter systems leading to yet unexplored types of qubits, using e.g. electrons on the surface of superfluid helium, impurity spins in fullerenes, and Majorana type qubits. The accompanying exercise class will deepen the understanding of the lecture topics and provides a forum to discuss open questions.

**Workload**

240 h consisting of attendance time (60 h), wrap-up of the lecture, working on the exercises and preparation of the exam (180 h).

**Literature**

- A. M. Zagorskin, Quantum Engineering, 2011
- Quantum Computing: Progress and Prospects, 2019
- P. Kranz, et al. A quantum engineer’s guide to superconducting qubits, 2019
Module: Solid State Quantum Computing, with Exercises (Minor) [M-PHYS-105872]

**Responsible:** Prof. Dr. Alexey Ustinov  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Condensed Matter

### Credits: 8  
### Grading scale: pass/fail  
### Recurrence: Each winter term  
### Duration: 1 term  
### Language: English  
### Level: 4  
### Version: 1

| Mandatory | T-PHYS-111805 | Solid State Quantum Computing, with Exercises (Minor) | 8 CR | Ustinov |

**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
Quantum mechanics 1, Solid state physics (Modern Physics II)

**Competence Goal**  
The students become familiar with the physical foundations of solid-state quantum computing technologies. They learn about types of quantum circuits based on qubits and resonators, their control, manipulation and measurement techniques. Active participation in the exercise class provides the ability to understand and mathematically analyze basic experiments in quantum information processing. This course is intended to be an introduction into the new interdisciplinary field called quantum engineering.

**Content**  
This course has the primary focus on experimental physics and covers the physical foundations of solid-state quantum computing technologies. Solid state quantum computing is a rapidly developing interdisciplinary field involving ideas from quantum mechanics, condensed matter physics, quantum optics, and quantum information processing. In the past few years, quantum computers turned from a dream into reality and offer fascinating opportunities for the future. While classical computers encode the information in bits, quantum computers are built using quantum bits, or qubits. The lecture course will review various types of qubits - quantum hardware that can be or is already used to build quantum computers based on solid-state technologies. We will start from a brief introduction in superconductivity to discuss then the most advanced modern technology based on superconducting quantum circuits. Such circuits with multiple qubits are currently being used in existing quantum computers implemented by Google, IBM, and other IT-companies. Besides superconductors, we will also talk about emerging solid-state quantum platforms such as semiconductor quantum dots, vacancy centers in diamond, solid-state impurity spins and other quantum two-level systems. These emerging versatile approaches are also capable of building primitive single- or two-qubit level circuits. Finally, we will briefly discuss interesting theoretical proposals of condensed matter systems leading to yet unexplored types of qubits, using e.g. electrons on the surface of superfluid helium, impurity spins in fullerenes, and Majorana type qubits. The accompanying exercise class will deepen the understanding of the lecture topics and provides a forum to discuss open questions.

**Workload**  
240 h consisting of attendance time (60 h) and wrap-up of the lecture and working on the exercises (180 h)

**Literature**
- A. M. Zagoskin, Quantum Engineering, 2011
- Quantum Computing: Progress and Prospects, 2019
Module: Solid State Quantum Technologies [M-PHYS-104857]

**Responsible:** Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104858 - Solid State Quantum Technologies (Minor) must not have been started.

**Competence Goal**

The development and comprehensive use of Quantum Technology is one of the most ambitious technological goals of today's science, with expected dramatic impact on the whole society and economy. The field of quantum information processing using solid state quantum bits (qubits) has witnessed an exponential growth during the last years. The current performances suggest that within a horizon of a few years, solid state quantum machines could outperform even the best classical machines for a few types of particularly hard tasks. During this class, the students will acquire a basic understanding of the principles of quantum information processing and the functioning of computers based on qubits, with an emphasis on experimental implementations using superconducting circuits and cavities and spin based solid state qubits. The supporting problems will cover in detail a broad set of calculations, from derivations of basic results, to solving practical problems one could encounter in a research laboratory.

**Content**

After a general introduction to the concepts of quantum information processing, we will present an overview of different experimental implementations. We will then focus on spin qubits and superconducting circuit qubits. We will discuss sources of loss and dephasing, and we will mention several strategies to increase the coherence of qubits. During the last few lectures, we will focus on advanced topics such as circuit quantum electrodynamics (cQED) and quantum optics in the microwave domain.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendation**

Basic knowledge of quantum mechanics

**Literature**

Will be announced in the lecture
4.181 Module: Solid State Quantum Technologies (Minor) [M-PHYS-104858]

Responsibility: Prof. Dr. Wolfgang Wernsdorfer
Organisation: KIT Department of Physics
Part of: Minor in Physics: Condensed Matter
Minor in Physics: Nanophysics

<table>
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<tr>
<td>T-PHYS-109890</td>
<td>Solid State Quantum Technologies</td>
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Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-104857 - Solid State Quantum Technologies must not have been started.

Competence Goal
The development and comprehensive use of Quantum Technology is one of the most ambitious technological goals of today's science, with expected dramatic impact on the whole society and economy. The field of quantum information processing using solid state quantum bits (qubits) has witnessed an exponential growth during the last years. The current performances suggest that within a horizon of a few years, solid state quantum machines could outperform even the best classical machines for a few types of particularly hard tasks. During this class, the students will acquire a basic understanding of the principles of quantum information processing and the functioning of computers based on qubits, with an emphasis on experimental implementations using superconducting circuits and cavities and spin based solid state qubits. The supporting problems will cover in detail a broad set of calculations, from derivations of basic results, to solving practical problems one could encounter in a research laboratory.

Content
After a general introduction to the concepts of quantum information processing, we will present an overview of different experimental implementations. We will then focus on spin qubits and superconducting circuit qubits. We will discuss sources of loss and dephasing, and we will mention several strategies to increase the coherence of qubits. During the last few lectures, we will focus on advanced topics such as circuit quantum electrodynamics (cQED) and quantum optics in the microwave domain.

Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and work on the exercises (180 hours).

Recommendation
Basic knowledge of quantum mechanics

Literature
Will be announced in the lecture
4.182 Module: Solid-State Optics [M-PHYS-102408]

**Responsible:** PD Dr. Michael Hetterich  
Prof. Dr. Heinz Kalt

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Optics and Photonics (mandatory)  
Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
Second Major in Physics: Optics and Photonics

**Credits** 8  
**Grading scale** Grade to a tenth  
**Recurrence** Each winter term  
**Duration** 1 term  
**Language** English  
**Level** 4  
**Version** 1

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module **M-PHYS-102409 - Solid-State Optics (Minor)** must not have been started.

**Competence Goal**

The students

- know the basic interaction processes between light and matter and are familiar with the polariton concept
- can explain the optical properties of insulators, semiconductors (including quantum structures) and metals
- comprehend the concept of the dielectric function and can utilize it to calculate relevant optical quantities
- are familiar with the classical Drude-Lorentz model and its implications for the optical properties of solids
- understand the relation between classical and quantum mechanical models for the dielectric function as well as the importance of the Kramers Kronig relations
- can explain near-band-edge optical spectra of semiconductors and insulators based on the concepts of joint density of states, oscillator strength, as well as excitonic effects
- are familiar with common experimental techniques of optical spectroscopy
- understand the origin of different optical nonlinearities and high-excitation effects as well as their mathematical description, their experimental realization and their applications
- comprehend the basics of group theory and can apply it to solid state optics

**Content**

Maxwell’s equations, refractive index, dispersion, dielectric function, extinction, absorption, reflection, continuity conditions at interfaces, anisotropic media and layered systems, Drude–Lorentz model, reststrahlen bands, Bloch states and band structure, perturbation theory of light–matter interaction, band to band transitions, joint density of states, van Hove singularities, phonon and exciton polaritons, plasmons, metals, semiconductor heterostructures, low-dimensional systems, group theory and selection rules, nonlinear optics, high-excitation effects in semiconductors, measurement of optical functions: Fourier spectroscopy, ellipsometry, modulation spectroscopy, photoluminescence, reflectometry, absorptivity.

**Workload**

240 hours, consisting of attendance time (60 hours) and follow-up work incl. preparation of the exam (180 hours)

**Recommendation**

Basic knowledge of solid-state physics and quantum mechanics is expected.
Literature

- H. Kalt, C. Klingshirn: Semiconductor Optics
- F. Wooten: Optical Properties of Solids
- P.K. Basu: Theory of optical processes in semiconductors
- H. Ibach and H. Lüth: Solid-State Physics
Module: Solid-State Optics (Minor) [M-PHYS-102409]

**Responsibility:**
PD Dr. Michael Hetterich
Prof. Dr. Heinz Kalt

**Organisation:**
KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Optics and Photonics

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**Competence Certificate**
The course credit for the physics minor will be an ungraded oral examination of the stated qualification objectives.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102408 - Solid-State Optics must not have been started.

**Competence Goal**
The students

- know the basic interaction processes between light and matter and are familiar with the polariton concept
- can explain the optical properties of insulators, semiconductors (including quantum structures) and metals
- comprehend the concept of the dielectric function and can utilize it to calculate relevant optical quantities
- are familiar with the classical Drude–Lorentz model and its implications for the optical properties of solids
- understand the relation between classical and quantum mechanical models for the dielectric function as well as the importance of the Kramers Kronig relations
- can explain near-band-edge optical spectra of semiconductors and insulators based on the concepts of joint density of states, oscillator strength, as well as excitonic effects
- are familiar with common experimental techniques of optical spectroscopy
- understand the origin of different optical nonlinearities and high-excitation effects as well as their mathematical description, their experimental realization and their applications
- comprehend the basics of group theory and can apply it to solid state optics

**Content**
Maxwell’s equations, refractive index, dispersion, dielectric function, extinction, absorption, reflection, continuity conditions at interfaces, anisotropic media and layered systems, Drude–Lorentz model, reststrahlen bands, Bloch states and band structure, perturbation theory of light–matter interaction, band to band transitions, joint density of states, van Hove singularities, phonon and exciton polaritons, plasmons, metals, semiconductor heterostructures, low-dimensional systems, group theory and selection rules, nonlinear optics, high-excitation effects in semiconductors, measurement of optical functions: Fourier spectroscopy, ellipsometry, modulation spectroscopy, photoluminescence, reflectometry, absorptivity.

**Workload**
240 hours, consisting of attendance time (60 hours) and follow-up work incl. preparation of the exam (180 hours)

**Recommendation**
Basic knowledge of solid-state physics and quantum mechanics is expected.

**Literature**

- H. Kalt, C. Klingshirn: Semiconductor Optics
- F. Wooten: Optical Properties of Solids
- P.K. Basu: Theory of optical processes in semiconductors
- H. Ibach and H. Lüth: Solid-State Physics
Module: Specialization Phase [M-PHYS-101396]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** Specialization Phase

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<td>Specialization Phase</td>
<td>15 CR</td>
<td>Studiendekan Physik</td>
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**Competence Certificate**

Study achievement, ungraded.

**Prerequisites**

The following subjects of the course of study have to be passed:

- Major in Physics
- Second Major in Physics
- Minor in Physics
- Non-Physics Elective
- Advanced Physics Laboratory Course

**Competence Goal**

Students acquire essential working techniques for the completion of their master's thesis; the working techniques are specific to the area of specialization.

**Workload**

approx. 450 hours
Module: Spin Transport in Nanostructures [M-PHYS-102293]

**Responsible:** apl. Prof. Dr. Detlef Beckmann

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

**Credits** 6

**Grading scale** Grade to a tenth

**Recurrence** Irregular

**Duration** 1 term

**Language** German

**Level** 4

**Version** 1

**Mandatory**

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<td>T-PHYS-104586</td>
<td>Spin Transport in Nanostructures</td>
<td>6 CR Beccmann</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105375 - Spin Transport in Nanostructures (Minor) must not have been started.

**Competence Goal**

The students know the basic concepts of spin-polarized transport and their application to transport properties in nanostructures. They are able to solve concrete problems from this subject area using the factual knowledge acquired in the lecture.

**Content**

The lecture will first introduce the basics of electronic transport and magnetism. Based on this, magnetoresistive effects in nanoscale structures important for spin electronics are discussed (giant magnetoresistance, spin accumulation, tunnel magnetoresistance). Further topics are magnetization dynamics (micromagnetics, spin torque, domain walls, spin waves) and the coupling of spin and thermal transport (spin caloritronics).

**Workload**

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

Will be mentioned in the lecture.
Module: Spin Transport in Nanostructures (Minor) [M-PHYS-105375]

**Responsible:** apl. Prof. Dr. Detlef Beckmann

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Condensed Matter
Minor in Physics: Nanophysics

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**Mandatory**

| T-PHYS-110858 | Spin Transport in Nanostructures (Minor) | 6 CR | Beckmann |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102293 - Spin Transport in Nanostructures must not have been started.

**Competence Goal**
The students know the basic concepts of spin-polarized transport and their application to transport properties in nanostructures. They are able to solve concrete problems from this subject area using the factual knowledge acquired in the lecture.

**Content**
The lecture will first introduce the basics of electronic transport and magnetism. Based on this, magnetoresistive effects in nanoscale structures important for spin electronics are discussed (giant magnetoresistance, spin accumulation, tunnel magnetoresistance). Further topics are magnetization dynamics (micromagnetics, spin torque, domain walls, spin waves) and the coupling of spin and thermal transport (spin caloritronics).

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture and preparation of the exercises (135 hours).

**Recommendation**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**
Will be mentioned in the lecture.
Module: Superconducting Nanostructures [M-PHYS-102191]

**Responsible:** apl. Prof. Dr. Detlef Beckmann

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Mandatory**

| T-PHYS-104513 | Superconducting Nanostructures | 6 CR | Beckmann |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-104723 - Superconducting Nanostructures (Minor) must not have been started.

**Competence Goal**

The students are introduced to the basic concepts of superconductivity and understand their application to transport properties in nanostructures. In the exercise, the students solve concrete problems from this subject area using the factual knowledge imparted in the lecture.

**Content**

In the lecture, the fundamentals of superconductivity are first discussed (BCS theory). These are applied to electronic transport properties of nanostructures whose dimensions are comparable to the coherence length of superconductivity. The main transport processes (tunneling, Andreev reflection, Josephson effect) are treated, the competition of superconductivity with other ground states (normal metal, ferromagnet) is discussed (proximity effect), and their interplay in complex nanostructures is highlighted. The fundamentals are illustrated by numerous examples from current research.

**Workload**

180 hours consisting of attendance time (45 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

Literature will be mentioned in the lecture.
Module: Superconducting Nanostructures (Minor) [M-PHYS-104723]

**Responsible:** apl. Prof. Dr. Detlef Beckmann

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Nanophysics

<table>
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<td>Superconducting Nanostructures (Minor)</td>
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**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102191 - Superconducting Nanostructures must not have been started.

**Competence Goal**

The students are introduced to the basic concepts of superconductivity and understand their application to transport properties in nanostructures. In the exercise, the students solve concrete problems from this subject area using the factual knowledge imparted in the lecture.

**Content**

In the lecture, the fundamentals of superconductivity are first discussed (BCS theory). These are applied to electronic transport properties of nanostructures whose dimensions are comparable to the coherence length of superconductivity. The main transport processes (tunneling, Andreev reflection, Josephson effect) are treated, the competition of superconductivity with other ground states (normal metal, ferromagnet) is discussed (proximity effect), and their interplay in complex nanostructures is highlighted. The fundamentals are illustrated by numerous examples from current research.

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of lecture and preparation of exercises (135 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

Literature will be mentioned in the lecture.
4.189 Module: Superconductivity, Josephson Effect and Applications, with Exercises [M-PHYS-105655]

**Responsible:** Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Condensed Matter Theory

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<td>T-PHYS-111293</td>
<td>Superconductivity, Josephson Effect and Applications, with Exercises</td>
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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105656 - Superconductivity, Josephson Effect and Applications, with Exercises (Minor) must not have been started.
2. The module M-PHYS-106584 - Superconductivity, Josephson Effect and Applications, without Exercises must not have been started.

**Competence Goal**

The students master the basic concepts of theory of superconductivity.

The students are able to analyze and structure problems in the field of superconductivity.

The students acquire deep understanding of the Josephson effect.

The students are able to solve problems related to coherent quantum dynamics in superconducting circuits with Josephson elements.

**Content**

This Module covers the theoretical description of the phenomenon of superconductivity along with the introduction into various applications of superconducting systems. In particular the following subjects will be covered:

- Phenomenology, Meissner effect and London equation
- Ginzburg-Landau theory
- BCS theory
- Electrodynamics of superconductors, Anderson-Higgs mechanism
- Josephson effect in tunnel junctions
- Andreev states and Josephson effect
- Macroscopic quantum coherence
- Josephson qubits
- Microwave optics in Josephson circuits
- Arrays of Josephson junctions

**Workload**

240 hours consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and preparation and follow-up of the exercises (180 h).
4.190 Module: Superconductivity, Josephson Effect and Applications, with Exercises (Minor) [M-PHYS-105656]

**Responsible:** Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Condensed Matter Theory

**Credits:** 8

**Grading scale:** pass/fail

**Recurrence:** Irregular

**Duration:** 1 term

**Language:** English

**Level:** 4

**Version:** 2

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-105655 - Superconductivity, Josephson Effect and Applications, with Exercises must not have been started.
2. The module M-PHYS-106584 - Superconductivity, Josephson Effect and Applications, without Exercises must not have been started.

**Competence Goal**
The students master the basic concepts of theory of superconductivity.
The students are able to analyze and structure problems in the field of superconductivity.
The students acquire deep understanding of the Josephson effect.
The students are able to solve problems related to coherent quantum dynamics in superconducting circuits with Josephson elements.

**Content**
This Module covers the theoretical description of the phenomenon of superconductivity along with the introduction into various applications of superconducting systems. In particular the following subjects will be covered:

- Phenomenology, Meissner effect and London equation
- Ginzburg-Landau theory
- BCS theory
- Electrodynamics of superconductors, Anderson-Higgs mechanism
- Josephson effect in tunnel junctions
- Andreev states and Josephson effect
- Macroscopic quantum coherence
- Josephson qubits
- Microwave optics in Josephson circuits
- Arrays of Josephson junctions

**Workload**
240 hours consisting of attendance time (60 h), follow-up of the lecture and preparation and follow-up of the exercises (180 h).
Module: Superconductivity, Josephson Effect and Applications, without Exercises [M-PHYS-106584]

**Responsible:** Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Condensed Matter Theory

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**Credits**

**Grading scale**

**Recurrence**

**Duration**

**Language**

**Level**

**Version**

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-105656 - Superconductivity, Josephson Effect and Applications, with Exercises (Minor) must not have been started.
2. The module M-PHYS-105655 - Superconductivity, Josephson Effect and Applications, with Exercises must not have been started.

**Competence Goal**

The students master the basic concepts of theory of superconductivity.

The students are able to analyze and structure problems in the field of superconductivity.

The students acquire deep understanding of the Josephson effect.

**Content**

This Module covers the theoretical description of the phenomenon of superconductivity along with the introduction into various applications of superconducting systems. In particular the following subjects will be covered:

- Phenomenology, Meissner effect and London equation
- Ginzburg-Landau theory
- BCS theory
- Electrodynamics of superconductors, Anderson-Higgs mechanism
- Josephson effect in tunnel junctions
- Andreev states and Josephson effect
- Macroscopic quantum coherence
- Josephson qubits
- Microwave optics in Josephson circuits
- Arrays of Josephson junctions

**Workload**

180 hours consisting of attendance time (45 h), wrap-up of the lecture incl. exam preparation and preparation and follow-up of the exercises (135 h).
4.192 Module: Supplementary Studies on Culture and Society [M-ZAK-106235]

**Responsible:** Dr. Christine Mielke  
Christine Myglas

**Organisation:**  
Part of: Additional Examinations

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**Election notes**

With the exception of the final oral exam and the practice module, students have to self-record the achievements obtained in the Supplementary Studies on Culture and Society in their study plan. ZAK records the achievements as "non-assigned" under "ÜQ/SQ-Leistungen". Further instructions on self-recording of achievements can be found in the FAQ at https://campus.studium.kit.edu/ and on the ZAK homepage at https://www.zak.kit.edu/begleitstudium-bak.php. The title of the examination and the amount of credits override the modules placeholders.

If you want to use ZAK achievements **both for your interdisciplinary qualifications and for the supplementary studies**, please record them in the interdisciplinary qualifications first. You can then get in contact with the ZAK study services (stg@zak.kit.edu) to also record them in your supplementary studies.

In the in-depth module, achievements have to be obtained in three different areas. The areas are as follows:

- Technology & Responsibility
- Doing Culture
- Media & Aesthetics
- Spheres of Life
- Global Cultures

You have to obtain two achievements with 3 credits each and one achievement with 5 credits. To self-record achievements in the in-depth module, you first have to elect the matching partial achievement.

**Note:** If you registered for the Supplementary Studies on Sustainable Development before April 1st, 2023, self-recording an achievement in this module counts as a request in the sense of §20 (2) of the regulations for the Supplementary Studies on Culture and Society. Your overall grade for the supplementary studies will thus be calculated as the average of the examination grades, not as the average of the module grades.

**Mandatory**

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**In-depth Module (Elective: 3 items)**

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<th>T-ZAK-112654</th>
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<td>T-ZAK-112658</td>
<td>In-depth Module - Global Cultures - Self Assignment BAK</td>
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<td>Oral Exam - Supplementary Studies on Culture and Society</td>
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<td>Mielke, Myglas</td>
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</table>

**Competence Certificate**

The monitoring is explained in the respective partial achievement. They are composed of:

- minutes
- presentations
- a seminar paper
- an internship report
- an oral examination

After successful completion of the supplementary studies, the graduates receive a graded certificate and a KIT certificate.
Prerequisites
The offer is study-accompanying and does not have to be completed within a defined period of time. Enrollment or acceptance for graduation must be present when registering for the final examination.

KIT students register for the supplementary studies by selecting this module in the student portal and self-checking a performance. In addition, registration for the individual courses is necessary, which is possible shortly before the beginning of each semester.

The course catalogue, statutes (study regulations), registration form for the oral exam, and guides for preparing the various written performance requirements can be found as downloads on the ZAK homepage at www.zak.kit.edu/begleitstudium-bak.

Competence Goal
Graduates of the Supplementary Studies on Culture and Society demonstrate a sound basic knowledge of conditions, procedures and concepts for analysing and shaping fundamental social development tasks in connection with cultural topics. They have gained a well-founded theoretical and practical insight into various cultural studies and interdisciplinary topics in the field of tension between culture, technology and society in the sense of an expanded concept of culture.

They are able to place the contents selected from the specialization module in the basic context as well as to analyse and evaluate the contents of the selected courses independently and exemplarily and to communicate about them scientifically in written and oral form. Graduates are able to analyse social topics and problem areas and critically reflect on them in a socially responsible and sustainable perspective.

Content
The Supplementary Studies on Culture and Society can be started from the 1st semester and is not limited in time. It comprises at least 3 semesters. The supplementary studies are divided into 3 modules (basics, in-depth studies, practice). A total of 22 credit points (ECTS) are earned.

The thematic elective areas of the supplementary studies are divided into the following 5 modules and their sub-topics:

Block 1 Technology & Responsibility
Value change / ethics of responsibility, technology development / history of technology, general ecology, sustainability

Block 2 Doing Culture
Cultural studies, cultural management, creative industries, cultural institutions, cultural policy

Block 3 Media & Aesthetics
Media communication, cultural aesthetics

Block 4 Spheres of Life
Cultural sociology, cultural heritage, architecture and urban planning, industrial science

Block 5 Global Cultures
Multiculturalism / interculturalism / transculturalism, science and culture

Module grade calculation
The overall grade of the supplementary studies is calculated as an average of the grades of the examination performances weighted with credit points.

In-depth Module
- presentation 1 (3 ECTS)
- presentation 2 (3 ECTS)
- seminar paper incl. presentation (5 ECTS)
- oral examination (4 ECTS)
Annotation
With the Supplementary Studies on Culture and Society, KIT provides a multidisciplinary study offer as an additional qualification, with which the respective specialized study program is supplemented by interdisciplinary basic knowledge and interdisciplinary orientation knowledge in the field of cultural studies, which is becoming increasingly important for all professions.

Within the framework of the supplementary studies, students acquire in-depth knowledge of various cultural studies and interdisciplinary subject areas in the field of tension between culture, technology and society. In addition to high culture in the classical sense, other cultural practices, common values and norms as well as historical perspectives of cultural developments and influences are considered.

In the courses, conditions, procedures and concepts for the analysis and design of fundamental social development tasks are acquired on the basis of an expanded concept of culture. This includes everything created by humans - also opinions, ideas, religious or other beliefs. The aim is to develop a modern concept of cultural diversity. This includes the cultural dimension of education, science and communication as well as the preservation of cultural heritage. (UNESCO, 1982)

According to § 16 of the statutes, a reference and a certificate are issued by the ZAK for the supplementary studies. The achievements are also shown in the transcript of records of the degree program and, upon request, in the certificate. They can also be recognized in the interdisciplinary qualifications (see elective information).

Workload
The workload is made up of the recommended number of hours for the individual modules:

- basic module approx. 90 h
- in-depth module approx. 340 h
- practical module approx. 120 h

total: approx. 550 h

Learning type
- lectures
- seminars
- workshops
- practical course

Literature
Recommended reading of primary and specialized literature will be determined individually by each instructor.
### 4.193 Module: Supplementary Studies on Sustainable Development [M-ZAK-106099]

**Responsible:** Dr. Christine Mielke  
Christine Myglas  

**Organisation:**  
Part of: Additional Examinations

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**Election notes**

With the exception of the final oral exam, students have to self-record the achievements obtained in the Supplementary Studies on Sustainable Development in their study plan. ZAK records the achievements as "non-assigned" under "ÜQ/SQ-Leistungen". Further instructions on self-recording of achievements can be found in the FAQ at [https://campus.studium.kit.edu/](https://campus.studium.kit.edu/) and on the ZAK homepage at [https://www.zak.kit.edu/begleitstudium-bene](https://www.zak.kit.edu/begleitstudium-bene). The title of the examination and the amount of credits override the modules placeholders.

If you want to use ZAK achievements **both for your interdisciplinary qualifications and for the supplementary studies**, please record them in the interdisciplinary qualifications first. You can then get in contact with the ZAK study services ([stg@zak.kit.edu](mailto:stg@zak.kit.edu)) to also record them in your supplementary studies.

In the elective module, you need to obtain 6 credits worth of achievements in two of the four areas:

- Sustainable Cities & Neighbourhoods
- Sustainable Assessment of Technology
- Subject, Body, Individual: The Other Side of Sustainability
- Sustainability in Culture, Economy & Society

Usually, two achievements with 3 credits each have to be obtained. To self-record achievements in the elective module, you first have to elect the matching partial achievement.

**Note:** If you registered for the Supplementary Studies on Sustainable Development before April 1st, 2023, self-recording an achievement in this module counts as a request in the sense of §19 (2) of the regulations for the Supplementary Studies on Sustainable Development. Your overall grade for the supplementary studies will thus be calculated as the average of the examination grades, not as the average of the module grades.

### Mandatory

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### Elective Module (Elective: at least 6 credits)

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### Mandatory

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<td>Oral Exam - Supplementary Studies on Sustainable Development</td>
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</table>
Competence Certificate

The monitoring is explained in the respective partial achievement.

They are composed of:

- protocols
- a reflection report
- presentations
- presentations
- the elaboration of a project work
- an individual term paper

Upon successful completion of the supplementary studies, graduates receive a graded report and a certificate issued by ZAK.

Prerequisites

The course is offered during the course of study and does not have to be completed within a defined period of time. Enrollment is required for all performance assessments of the modules of the supplementary studies. Participation in the supplementary studies is regulated by § 3 of the statutes.

KIT students register for the supplementary studies by selecting this module in the student portal and self-booking a performance. Registration for courses, performance assessments and examinations is regulated by § 6 of the Statutes and is usually possible shortly before the beginning of the semester.

The course catalogue, statutes (study regulations), registration form for the oral exam and guidelines for preparing the various written performance requirements can be found as downloads on the ZAK homepage at http://www.zak.kit.edu/begleitstudium-bene.

Competence Goal

Graduates of the supplementary studies in sustainable development acquire additional practical and professional competencies. Thus, the supplementary study program enables the acquisition of basics and initial experience in project management, trains teamwork skills, presentation skills and self-reflection, and also creates a fundamental understanding of sustainability that is relevant for all professional fields.

Graduates are able to analyse social topics and problem areas and critically reflect on them in a socially responsible and sustainable perspective. They are able to place the contents selected from the modules "Elective" and "Advanced" in the basic context as well as to independently and exemplarily analyse and evaluate the contents of the selected courses and to scientifically communicate about them in written and oral form.

Content

The supplementary study program Sustainable Development can be started from the 1st semester and is not limited in time. The wide range of courses offered by ZAK makes it possible to complete the program usually within three semesters. The supplementary studies comprise 19 credit points (LP). It consists of three modules: Basic Module, Elective Module and Advanced Module.

The thematic elective areas of the supplementary studies are divided into the following 4 modules and their subtopics in Module 2 (elective module):

Block 1 Sustainable Cities and Neighbourhoods

The courses provide an overview of the interaction of social, ecological, and economic dynamics in the microcosm of the city.

Block 2 Sustainability Assessment of Technology

Mostly based on ongoing research activities, methods and approaches of technology assessment are elaborated.

Block 3 Subject, Body, Individual: The other Side of Sustainability

Different approaches are presented to the individual perception, experience, shaping and responsibility of relationships to the environment and to oneself.

Block 4 Sustainability in Culture, Economy & Society

Courses usually have an interdisciplinary approach, but may also focus on one of the areas of culture, economics or society, both in application and in theory.

The core of the supplementary studies is a case study in the specialization area. In this project seminar, students conduct sustainability research with practical relevance themselves. The case study is supplemented by an oral examination with two topics from module 2 (elective module) and module 3 (in-depth module).
Module grade calculation
The overall grade of the supplementary studies is calculated as an average of the grades of the examination performances weighted with credit points.

 Elective module
- Presentation 1 (3 ECTS)
- Presentation 2 (3 ECTS)

 Advanced module
- individual term paper (6 ECTS)
- oral examination (4 ECTS)

 Annotation
The Supplementary Studies on Sustainable Development at KIT is based on the conviction that a long-term socially and ecologically compatible coexistence in the global world is only possible if knowledge about necessary changes in science, economy and society is acquired and applied.

The interdisciplinary and transdisciplinary Studies on Sustainable Development enables diverse access to transformation knowledge as well as basic principles and application areas of sustainable development. According to the statutes § 16, a certificate is issued by the ZAK for the complementary studies.

The achievements are also shown in the transcript of records of the degree program and, upon request, in the certificate. They can also be recognized in the interdisciplinary qualifications (see elective information).

In the specialised studies, modules and partial achievements can be recognised within the framework of the additional achievements or e.g. the interdisciplinary qualifications. This must be regulated via the respective subject study programme.

The focus is on experience- and application-oriented knowledge and competences, but theories and methods are also learned. The aim is to be able to represent one’s own actions as a student, researcher and later decision-maker as well as an individual and part of society under the aspect of sustainability.

Sustainability is understood as a guiding principle to which economic, scientific, social and individual actions should be oriented. According to this, the long-term and socially just use of natural resources and the material environment for a positive development of global society can only be addressed by means of integrative concepts. Therefore, “education for sustainable development” in the sense of the United Nations programme plays just as central a role as the goal of promoting “cultures of sustainability”. For this purpose, practice-centred and research-based learning of sustainability is made possible and the broad concept of culture established at ZAK is used, which understands culture as habitual behaviour, lifestyle and changing context for social actions.

The supplementary study programme conveys the basics of project management, trains teamwork skills, presentation skills and self-reflection. Complementary to the specialised studies at KIT, it creates a fundamental understanding of sustainability, which is important for all professional fields. Integrative concepts and methods are essential: in order to use natural resources in the long term and to shape the global future in a socially just way, not only different disciplines, but also citizens, practitioners and institutions must work together.

Workload
The workload is made up of the number of hours of the individual modules:

- Basic module approx. 180 h
- Elective module approx. 150 h
- Consolidation module approx. 180 h

Total: approx. 510 h

Learning type
- lectures
- seminars
- workshops

Literature
Recommended reading of primary and specialist literature is determined individually by the respective lecturer.
Module: Surface Science, with Exercises [M-PHYS-106482]

**Responsible:** TT-Prof. Dr. Philip Willke  
Prof. Dr. Wulf Wulfhekel  
PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Nanophysics (Required Elective Nanophysics)  
Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)  
Second Major in Physics: Nanophysics (Elective Nanophysics)

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<td>Surface Science, with Exercises</td>
<td>10 CR Willke, Wulfhekel, Zakeri-Lori</td>
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</table>

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-106483 - Surface Science, without Exercises must not have been started.
2. The module M-PHYS-106484 - Surface Science, with Exercises (Minor) must not have been started.

**Competence Goal**

Students are introduced to the basic concepts of surface science, they master the relevant theoretical concepts and understand the concepts and measurement methods of surface science as well as their application. In groups they solve concrete problems of surface science using the factual knowledge acquired in the lecture.

**Content**

In the lecture, physics at surfaces and interfaces as well as the physical chemistry at surfaces are discussed. Starting with the two-dimensional space group, the structure of surfaces is discussed as well as effects arising from symmetry breaking at surfaces and interfaces. Furthermore, layer growth and modification of layer growth using various techniques will be discussed. The main part of the lecture deals with the electronic structure of two-dimensional systems and nanostructures as well as the experimental techniques of surface science.

**Workload**

300 hours consisting of attendance time (75 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (225 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

- K. Oura, V.G. Lifshits, A.A. Saranin, A.V. Zotov, M. Katayama, Surface Science: An Introduction, Springer
- H. Ibach, Physics of Surfaces and Interfaces, Springer
Module: Surface Science, with Exercises (Minor) [M-PHYS-106484]

**Responsible:** TT-Prof. Dr. Philip Willke  
Prof. Dr. Wulf Wulfhekel  
PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:**  
Minor in Physics: Condensed Matter  
Minor in Physics: Nanophysics

---

### Credits
10

**Grading scale**  
pass/fail

**Recurrence**  
Irregular

**Duration**  
1 term

**Language**  
English

**Level**  
4

**Version**  
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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-106482 - Surface Science, with Exercises must not have been started.
2. The module M-PHYS-106483 - Surface Science, without Exercises must not have been started.

**Competence Goal**  
Students are introduced to the basic concepts of surface science, they master the relevant theoretical concepts and understand the concepts and measurement methods of surface science as well as their application. In groups they solve concrete problems of surface science using the factual knowledge acquired in the lecture.

**Content**  
In the lecture, physics at surfaces and interfaces as well as the physical chemistry at surfaces are discussed. Starting with the two-dimensional space group, the structure of surfaces is discussed as well as effects arising from symmetry breaking at surfaces and interfaces. Furthermore, layer growth and modification of layer growth using various techniques will be discussed. The main part of the lecture deals with the electronic structure of two-dimensional systems and nanostructures as well as the experimental techniques of surface science.

**Workload**  
300 hours consisting of attendance time (75 hours), wrap-up of lecture and preparation of exercises (225 hours).

**Recommendation**  
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

- K. Oura, V.G. Lifshits, A.A. Sararin, A.V. Zotov, M. Katayama, Surface Science: An Introduction, Springer
- H. Ibach, Physics of Surfaces and Interfaces, Springer
Module: Surface Science, without Exercises [M-PHYS-106483]

**Responsible:**
- TT-Prof. Dr. Philip Willke
- Prof. Dr. Wulf Wulfhekel
- PD Dr. Khalil Zakeri-Lori

**Organisation:**
- KIT Department of Physics

**Part of:**
- Major in Physics: Condensed Matter (Elective Condensed Matter)
- Major in Physics: Nanophysics (Required Elective Nanophysics)
- Second Major in Physics: Condensed Matter (Required Elective Condensed Matter)
- Second Major in Physics: Nanophysics (Elective Nanophysics)

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**Mandatory**

| T-PHYS-113099 | Surface Science, without Exercises | 8 CR | Willke, Wulfhekel, Zakeri-Lori |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

None

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-106482 - Surface Science, with Exercises must not have been started.
2. The module M-PHYS-106484 - Surface Science, with Exercises (Minor) must not have been started.

**Competence Goal**

Students are introduced to the basic concepts of surface science, master the relevant theoretical concepts, and understand the concepts and measurement methods of surface science and their applications.

**Content**

In the lecture, physics at surfaces and interfaces as well as the physical chemistry at surfaces are discussed. Starting with the two-dimensional space group, the structure of surfaces is discussed as well as effects arising from symmetry breaking at surfaces and interfaces. Furthermore, layer growth and modification of layer growth using various techniques will be discussed. The main part of the lecture deals with the electronic structure of two-dimensional systems and nanostructures as well as the experimental techniques of surface science.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of lecture incl. exam preparation (180 hours).

**Recommendation**

Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**

- K. Oura, V.G. Lifshits, A.A. Saranin, A.V. Zotov, M. Katayama, Surface Science: An Introduction, Springer
- H. Ibach, Physics of Surfaces and Interfaces, Springer
Module: Symmetries and Groups [M-PHYS-102317]

Responsibility: Prof. Dr. Ulrich Nierste
Organisation: KIT Department of Physics
Part of: Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
Second Major in Physics: Theoretical Particle Physics

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M Mandatory
T-PHYS-104596 Symmetries and Groups 8 CR Nierste

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:
1. The module M-PHYS-102315 - Symmetries, Groups and Extended Gauge Theories must not have been started.
2. The module M-PHYS-102316 - Symmetries, Groups and Extended Gauge Theories (Minor) must not have been started.
3. The module M-PHYS-102318 - Symmetries and Groups (Minor) must not have been started.

Competence Goal
Learning the methodology of group theory. Ability to solve complex mathematical problems such as the classification of Lie groups.

Content
Lie groups and their representations, Lie algebras, Poincaré group, discrete groups, left-right symmetry, grand unified theories.

Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

Recommendation
Good knowledge of quantum mechanics I. For the last third, "extended gauge theories", previous knowledge of theoretical particle physics is required.

Literature
To be stated in the lecture.
### Module: Symmetries and Groups (Minor) [M-PHYS-102318]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102315 - Symmetries, Groups and Extended Gauge Theories must not have been started.
2. The module M-PHYS-102316 - Symmetries, Groups and Extended Gauge Theories (Minor) must not have been started.
3. The module M-PHYS-102317 - Symmetries and Groups must not have been started.

**Competence Goal**  
Learning the methodology of group theory  
Ability to solve complex mathematical problems such as the classification of Lie groups.

**Content**  
Lie groups and their representations, Lie algebras, Poincaré group, discrete groups, left-right symmetry, grand unified theories.

**Workload**  
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

**Recommendation**  
Good knowledge of quantum mechanics I. For the last third, "extended gauge theories", previous knowledge of theoretical particle physics is required.

**Literature**  
To be stated in the lecture.
Module: Symmetries, Groups and Extended Gauge Theories [M-PHYS-102315]

Responsible: Prof. Dr. Ulrich Nierste
Organisation: KIT Department of Physics
Part of: Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)
  Second Major in Physics: Theoretical Particle Physics

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Mandatory

| T-PHYS-102393 Symmetries, Groups and Extended Gauge Theories | 12 CR Nierste |

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102316 - Symmetries, Groups and Extended Gauge Theories (Minor) must not have been started.
2. The module M-PHYS-102317 - Symmetries and Groups must not have been started.
3. The module M-PHYS-102318 - Symmetries and Groups (Minor) must not have been started.

Competence Goal
Learning the methodology of group theory. Ability to solve complex mathematical problems such as classification of Lie groups, understanding the concepts of extended gauge theories.

Content
Lie groups and their representations, Lie algebras, Poincaré group, discrete groups, left-right symmetry, grand unified theories.

Workload
360 hours consisting of attendance time (90 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (270 hours)

Recommendation
Good knowledge of quantum mechanics I. For the last third, "extended gauge theories", previous knowledge of theoretical particle physics is required.

Literature
To be stated in the lecture.
# 4.200 Module: Symmetries, Groups and Extended Gauge Theories (Minor) [M-PHYS-102316]

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### Competence Certificate

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

### Prerequisites

none

### Modeled Conditions

The following conditions have to be fulfilled:

1. The module M-PHYS-102315 - Symmetries, Groups and Extended Gauge Theories must not have been started.
2. The module M-PHYS-102317 - Symmetries and Groups must not have been started.
3. The module M-PHYS-102318 - Symmetries and Groups (Minor) must not have been started.

### Competence Goal

Learning the methodology of group theory Ability to solve complex mathematical problems such as classification of Lie groups, understanding the concepts of extended gauge theories.

### Content

Lie groups and their representations, Lie algebras, Poincaré group, discrete groups, left-right symmetry, grand unified theories.

### Workload

360 hours consisting of attendance time (90 hours), wrap-up of the lecture and preparation of the exercises (270 hours).

### Recommendation

Good knowledge of quantum mechanics I. For the last third, "extended gauge theories", previous knowledge of theoretical particle physics is required.

### Literature

To be stated in the lecture.
4.201 Module: The ABC of DFT [M-PHYS-102984]

**Responsible:**
Prof. Dr. Carsten Rockstuhl
Prof. Dr. Wolfgang Wenzel

**Organisation:**
KIT Department of Physics

**Part of:**
Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
Understanding of basic numerical methods in density functional theory and the ability to apply them to solve physical problems in solid state physics such as the description of charge transport or magnetism. Emphasis is placed on acquiring the skills for independent simulation execution, subsequent data analysis, physical interpretation and, if possible, linkage with experimental investigations.

**Content**
With ever advancing computational power, it becomes possible to determine the electronic structure of increasingly complex systems relevant to solid state physics and materials science. Here we introduce Density Functional Theory (DFT) by explaining the basic underlying concepts, present examples of its application and its shortcomings and outline the most promising improvement paths. DFT will be applied to charge transport and magnetism related problems. As DFT makes it possible to treat fairly large systems (up to a few thousand of electrons) it enables direct comparison to experiment for many important applications. Both periodic, crystalline systems and localized single molecule in vacuum will be addressed with a special focus on systems with reduced dimensionality, such as surfaces and interfaces. Where applicable, comparisons to experiment and possible deployments will be presented. Some of the topics that will be addressed are:

- Basic concepts underpinning the DFT
- Calculations of band structure and density of states (DOS) of (hybrid) graphene materials.
- Treatment of magnetism within DFT, with examples of both bulk and molecular magnetism.
- Charge transport, with examples of both ballistic and disordered hopping transport.
- Beyond ground state DFT: Time Dependent DFT, GW, ...

**Workload**
180 h consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and working on the exercises (120 h)

**Recommendation**
Basic knowledge of solid state theory, quantum mechanics, and thermodynamics is assumed.

**Literature**
Will be mentioned in the lecture.
4.202 Module: Theoretical Molecular Biophysics, with Seminar [M-PHYS-102169]

**Responsible:** Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102170 - Theoretical Molecular Biophysics, with Seminar (Minor) must not have been started.
2. The module M-PHYS-102171 - Theoretical Molecular Biophysics, without Seminar must not have been started.
3. The module M-PHYS-102172 - Theoretical Molecular Biophysics, without Seminar (Minor) must not have been started.

**Competence Goal**

The students:

- can describe the structure of biopolymers based on their components
- understand the physical interactions that determine the structure and function of biopolymers
- know models for structure formation and function of biopolymers, especially proteins and DNA.
- know methods for the simulation of structure formation and function of biopolymers, especially molecular dynamics and their technical implementation
- can apply these methods to simple problems of the teaching content
- know methods for computer-aided drug development
- know basic bioinformatics methods for protein and DNA structure prediction
- are able to critically evaluate the procedures in the context of their application
- can understand a special topic within the teaching content on the basis of scientific literature and present it in a lecture or a paper
- can critically evaluate the scientific results of this special topic

**Content**

The students are introduced to current issues in molecular biophysics in the border area between biology, chemistry and physics. After an introduction to the composition and structure of biopolymers, especially proteins and DNA, the physical principles of structure formation and function are presented. Afterwards biophysical basics and biochemical models for the modelling of proteins and DNA in their physiological environment are introduced. A central teaching content is the introduction to simulation methods for biopolymers (molecular dynamics, Monte Carlo method) and the biophysical models used for this (force fields) and their application in the exercises. In addition to the basic methods, modern extensions (Free-Energy-Perturbation Theory, Umbrella-Sampling, Metadynamics) are discussed. Students will be introduced to the application of these methods to important questions in molecular biophysics, including protein folding, protein structure prediction, DNA structure prediction and computer-aided drug development.

**Workload**

240 hours composed of attendance time (60), wrap-up of the lectures incl. preparation of the oral exam and solving the exercises (120), preparation of the seminar or writing a report (60)

**Recommendation**

Knowledge of thermodynamics
Literature

- Daune: Molecular Biophysics
- Branden, Tooze: Introduction to Protein Structure

Further literature will be given in the lecture
4.203 Module: Theoretical Molecular Biophysics, with Seminar (Minor) [M-PHYS-102170]

**Responsibility:** Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Nanophysics
- Minor in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-102420 | Theoretical Molecular Biophysics, with Seminar (Minor) | 8 CR Wenzel |

**Competence Certificate**

50% of the points attainable in the exercise sheets, presentation and short lectures within the framework of the lecture/exercise.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102169 - Theoretical Molecular Biophysics, with Seminar must not have been started.
2. The module M-PHYS-102171 - Theoretical Molecular Biophysics, without Seminar must not have been started.
3. The module M-PHYS-102172 - Theoretical Molecular Biophysics, without Seminar (Minor) must not have been started.

**Competence Goal**

The students:

- can describe the structure of biopolymers based on their components
- understand the physical interactions that determine the structure and function of biopolymers
- know models for structure formation and function of biopolymers, especially proteins and DNA.
- know methods for the simulation of structure formation and function of biopolymers, especially molecular dynamics and their technical implementation
- can apply these methods to simple problems of the teaching content
- know methods for computer-aided drug development
- know basic bioinformatics methods for protein and DNA structure prediction
- are able to critically evaluate the procedures in the context of their application
- can understand a special topic within the teaching content on the basis of scientific literature and present it in a lecture or a paper
- can critically evaluate the scientific results of this special topic

**Content**

The students are introduced to current issues in molecular biophysics in the border area between biology, chemistry and physics. After an introduction to the composition and structure of biopolymers, especially proteins and DNA, the physical principles of structure formation and function are presented. Afterwards biophysical basics and biochemical models for the modelling of proteins and DNA in their physiological environment are introduced. A central teaching content is the introduction to simulation methods for biopolymers (molecular dynamics, Monte Carlo method) and the biophysical models used for this (force fields) and their application in the exercises. In addition to the basic methods, modern extensions (Free-Energy-Perturbation Theory, Umbrella-Sampling, Metadynamics) are discussed. Students will be introduced to the application of these methods to important questions in molecular biophysics, including protein folding, protein structure prediction, DNA structure prediction and computer-aided drug development.

**Workload**

240 hours composed of attendance time (60 hours), wrap-up of the lectures and solving the exercises (120 hours), preparation of the seminar or writing a report (60 hours)

**Recommendation**

Knowledge of thermodynamics
Literature

- Daune: Molecular Biophysics
- Branden, Tooze: Introduction to Protein Structure

Further literature will be given in the lecture
Module: Theoretical Molecular Biophysics, without Seminar [M-PHYS-102171]

**Responsibility:** Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-104473 | Theoretical Molecular Biophysics, without Seminar | 6 CR | Wenzel |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102169 - Theoretical Molecular Biophysics, with Seminar must not have been started.
2. The module M-PHYS-102170 - Theoretical Molecular Biophysics, with Seminar (Minor) must not have been started.
3. The module M-PHYS-102172 - Theoretical Molecular Biophysics, without Seminar (Minor) must not have been started.

**Competence Goal**

The students:

- can describe the structure of biopolymers based on their components
- understand the physical interactions that determine the structure and function of biopolymers
- know models for structure formation and function of biopolymers, especially proteins and DNA.
- know methods for the simulation of structure formation and function of biopolymers, especially molecular dynamics and their technical implementation
- can apply these methods to simple problems of the teaching content
- know methods for computer-aided drug development
- know basic bioinformatics methods for protein and DNA structure prediction
- are able to critically evaluate the procedures in the context of their application

**Content**

The students are introduced to current issues in molecular biophysics in the border area between biology, chemistry and physics. After an introduction to the composition and structure of biopolymers, especially proteins and DNA, the physical principles of structure formation and function are presented. Afterwards biophysical basics and biochemical models for the modelling of proteins and DNA in their physiological environment are introduced. A central teaching content is the introduction to simulation methods for biopolymers (molecular dynamics, Monte Carlo method) and the biophysical models used for this (force fields) and their application in the exercises. In addition to the basic methods, modern extensions (Free-Energy-Perturbation Theory, Umbrella-Sampling, Metadynamics) are discussed. Students will be introduced to the application of these methods to important questions in molecular biophysics, including protein folding, protein structure prediction, DNA structure prediction and computer-aided drug development.

**Workload**

180 hours composed of attendance time (60), wrap-up of the lectures incl. preparation of the oral exam and solving the exercises (120)

**Recommendation**

Knowledge of thermodynamics
Literature

- Daune: Molecular Biophysics
- Branden, Tooze: Introduction to Protein Structure

Further literature will be given in the lecture
4.205 Module: Theoretical Molecular Biophysics, without Seminar (Minor) [M-PHYS-102172]

**Responsible:** Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Nanophysics
- Minor in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-104474 | Theoretical Molecular Biophysics, without Seminar (Minor) | 6 CR | Wenzel |

**Competence Certificate**

50% of the points achievable in the exercise sheets

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102169 - Theoretical Molecular Biophysics, with Seminar must not have been started.
2. The module M-PHYS-102170 - Theoretical Molecular Biophysics, with Seminar (Minor) must not have been started.
3. The module M-PHYS-102171 - Theoretical Molecular Biophysics, without Seminar must not have been started.

**Competence Goal**

The students:

- can describe the structure of biopolymers based on their components
- understand the physical interactions that determine the structure and function of biopolymers
- know models for structure formation and function of biopolymers, especially proteins and DNA.
- know methods for the simulation of structure formation and function of biopolymers, especially molecular dynamics and their technical implementation
- can apply these methods to simple problems of the teaching content
- know methods for computer-aided drug development
- know basic bioinformatics methods for protein and DNA structure prediction
- are able to critically evaluate the procedures in the context of their application

**Content**

The students are introduced to current issues in molecular biophysics in the border area between biology, chemistry and physics. After an introduction to the composition and structure of biopolymers, especially proteins and DNA, the physical principles of structure formation and function are presented. Afterwards biophysical basics and biochemical models for the modelling of proteins and DNA in their physiological environment are introduced. A central teaching content is the introduction to simulation methods for biopolymers (molecular dynamics, Monte Carlo method) and the biophysical models used for this (force fields) and their application in the exercises. In addition to the basic methods, modern extensions (Free-Energy-Perturbation Theory, Umbrella-Sampling, Metadynamics) are discussed. Students will be introduced to the application of these methods to important questions in molecular biophysics, including protein folding, protein structure prediction, DNA structure prediction and computer-aided drug development.

**Workload**

180 hours composed of attendance time (60), wrap-up of the lectures and solving the exercises (120)

**Recommendation**

Knowledge of thermodynamics

**Literature**

- Daune: Molecular Biophysics
- Branden, Tooze: Introduction to Protein Structure

Further literature will be given in the lecture
Module: Theoretical Nanooptics [M-PHYS-102295]

**Responsibilities:**
- Prof. Dr. Markus Garst
- Prof. Dr. Carsten Rockstuhl

**Organisation:**
KIT Department of Physics

**Part of:**
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics
- Second Major in Physics: Condensed Matter Theory

**Credits:** 6

**Grading scale:** Grade to a tenth

**Recurrence:** Irregular

**Duration:** 1 term

**Language:** English

**Level:** 4

**Version:** 1

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-103177 - Theoretical Nanooptics (Minor) must not have been started.

**Competence Goal**
The properties of light at the nanoscale can be controlled by various means. The aim of this lecture is to familiarize the students with the different possibilities that rely on nanostructured dielectric or metallic materials and to outline on solid mathematical grounds the analytical description of observable effects. The lecture is meant as a complementary source of education to experimental lecture. It shall provide the students with the necessary skills to work themselves in the field of theoretical nanooptics.

**Content**

- Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections.
- Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates.
- Properties of plasmonic nanoparticles and the ability to tune their properties
- Notion of optical antennas and the discussion of their basic characteristics
- Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays.
- Discussion of metamaterials (unit cells, homogenization, light propagation, applications)
- Transformation optics
- Analytical modeling and phenomenological tools to describe nanooptical systems

**Workload**
180 hours composed of active time (45), wrap-up of the lecture incl. preparation of the examination and the exercises (135)

**Recommendation**
Solid mathematical background, good knowledge of classical electromagnetism and theoretical optics.
Module: Theoretical Nanooptics [M-PHYS-102295]

Literature

- L. Novotny and B. Hecht, Principle of Nano-Optics, Cambridge
- S. A. Maier, Plasmonics, Springer
4.207 Module: Theoretical Nanooptics (Minor) [M-PHYS-103177]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:**  
Minor in Physics: Nanophysics  
Minor in Physics: Optics and Photonics  
Minor in Physics: Condensed Matter Theory

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**Mandatory**

| T-PHYS-106311 | Theoretical Nanooptics (Minor) | 6 CR | Garst, Rockstuhl |

**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102295 - Theoretical Nanooptics must not have been started.

**Competence Goal**

The properties of light at the nanoscale can be controlled by various means. The aim of this lecture is to familiarize the students with the different possibilities that rely on nanostructured dielectric or metallic materials and to outline on solid mathematical grounds the analytical description of observable effects. The lecture is meant as a complementary source of education to experimental lecture. It shall provide the students with the necessary skills to work themselves in the field of theoretical nanooptics.

**Content**

- Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections.
- Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates.
- Properties of plasmonic nanoparticles and the ability to tune their properties
- Notion of optical antennas and the discussion of their basic characteristics
- Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays.
- Discussion of metamaterials (unit cells, homogenization, light propagation, applications)
- Transformation optics
- Analytical modeling and phenomenological tools to describe nanooptical systems

**Workload**

180 hours composed of active time (45), wrap-up of the lecture and the exercises (135)

**Recommendation**

Solid mathematical background, good knowledge of classical electromagnetism and theoretical optics.

**Literature**

- L. Novotny and B. Hecht, Principle of Nano-Optics, Cambridge
- S. A. Maier, Plasmonics, Springer
4.208 Module: Theoretical Optics [M-PHYS-102277]

**Responsible:** PD Dr. Boris Narozhnyy  
Prof. Dr. Carsten Rockstuhl  

**Organisation:** KIT Department of Physics  

**Part of:**  
- Major in Physics: Nanophysics (Elective Nanophysics)  
- Major in Physics: Optics and Photonics (mandatory)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)  
- Second Major in Physics: Optics and Photonics

**Credits**  
6  

**Grading scale**  
Grade to a tenth  

**Recurrence**  
Each summer term  

**Duration**  
1 term  

**Language**  
English  

**Level**  
4  

**Version**  
1

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102279 - Theoretical Optics (Minor) must not have been started.

**Competence Goal**

The students deepen their knowledge about the theory and the mathematical tools in optics and photonics. They learn how to apply these tools to describe fundamental phenomena and how to predict observable quantities that reflect the actual physics from the theory by way of a corresponding purposeful mathematical analyses. They learn how to solve problems of both, interpretative and predictive nature with regards to model systems and real life situations.

**Content**

- Review of Electromagnetism (Maxwell’s Equations, Stress Tensor, Material Properties, Kramers-Kronig Relation, Wave Propagation, Poynting’s Theorem)  
- Crystal Optics (Polarization, Anisotropic Media, Fresnel Equation, Applications)  
- Classical Coherence Theory (Elementary Coherence Phenomena, Theory of Stochastic Processes, Correlation Functions)  
- Quantum Optics and Quantum Optical Coherence Theory (Review of Quantum Mechanics, Quantization of the EM Field, Quantum Coherence Functions)

**Annotation**

For students of the KIT Faculty of Computer Science: The exams in this module have to be registered via admissions from ISS (KIT Faculty of Computer Science). For this, an e-mail with matriculation numbers and name of the desired exam to Beratung-informatik@informatik.kit.edu is sufficient.

**Workload**

180 hours composed of active time (45 hours), wrap-up of the lecture incl. preparation of the examination (135 hours)

**Recommendation**

Solid mathematical background, good knowledge of classical electromagnetism and basic knowledge of quantum mechanics.
Literature

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Introduction to Fourier Optics" Joseph W. Goodman
- "Introduction to the Theory of Coherence and Polarization of Light" Emil Wolf
- "The Quantum Theory of Light" Rodney Loudon
Module: Theoretical Optics (Minor) [M-PHYS-102279]

**Responsible:** PD Dr. Boris Narozhnyy  
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:**  
Minor in Physics: Nanophysics  
Minor in Physics: Optics and Photonics

**Credits:** 6  
**Grading scale:** pass/fail  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** English  
**Level:** 4  
**Version:** 1

**Mandatory**

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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102277 - Theoretical Optics must not have been started.

**Competence Goal**  
The students deepen their knowledge about the theory and the mathematical tools in optics and photonics. They learn how to apply these tools to describe fundamental phenomena and how to predict observable quantities that reflect the actual physics from the theory by way of a corresponding purposeful mathematical analyses. They learn how to solve problems of both, interpretative and predictive nature with regards to model systems and real life situations.

**Content**

- Review of Electromagnetism (Maxwell’s Equations, Stress Tensor, Material Properties, Kramers-Kronig Relation, Wave Propagation, Poynting’s Theorem)
- Crystal Optics (Polarization, Anisotropic Media, Fresnel Equation, Applications)
- Classical Coherence Theory (Elementary Coherence Phenomena, Theory of Stochastic Processes, Correlation Functions)
- Quantum Optics and Quantum Optical Coherence Theory (Review of Quantum Mechanics, Quantization of the EM Field, Quantum Coherence Functions)

**Workload**  
180 hours composed of active time (45 hours), wrap-up of the lecture and the examination (135 hours)

**Recommendation**  
Solid mathematical background, good knowledge of classical electromagnetism and basic knowledge of quantum mechanics.

**Literature**

- "Classical Electrodynamics" John David Jackson  
- "Theoretical Optics: An Introduction" Hartmann Römer  
- "Introduction to Fourier Optics" Joseph W. Goodman  
- "Introduction to the Theory of Coherence and Polarization of Light" Emil Wolf  
- "The Quantum Theory of Light" Rodney Loudon
Module: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises [M-PHYS-102033]

**4.210 Module: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises [M-PHYS-102033]**

**Responsible:**
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner
- Prof. Dr. Ulrich Nierste
- Prof. Dr. Matthias Steinhauser

**Organisation:**
KIT Department of Physics

**Part of:**
- Major in Physics: Theoretical Particle Physics (Required Theoretical Particle Physics)
- Second Major in Physics: Theoretical Particle Physics

**Credits:** 12

**Grading scale:** Grade to a tenth

**Recurrence:** Each winter term

**Duration:** 1 term

**Language:** English

**Level:** 4

**Version:** 1

**Mandatory**

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises must not have been started.
2. The module M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises must not have been started.
3. The module M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises must not have been started.
4. The module M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) must not have been started.
5. The module M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) must not have been started.

**Competence Goal**

The student is introduced to the basic concepts of Relativistic Quantum Field Theory, masters the relevant theoretical concepts and can apply the computational methods. The student applies his/her knowledge to physical problems and can calculate simple processes of QED. The students deepen their knowledge in the exercises coordinated with the lecture.

**Content**

Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

**Workload**

360 h consisting of attendance time (90 h), wrap-up of the lecture incl. exam preparation and working on the exercises (270 h)

**Recommendation**

Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

**Literature**

- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory
- L. Ryder, Quantum Field Theory
4.211 Module: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) [M-PHYS-102037]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-102540 | Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) | 12 CR | Heinrich, Melnikov, Mühlleitner, Nierste, Steinhauser |

**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises must not have been started.
2. The module M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises must not have been started.
3. The module M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises must not have been started.
4. The module M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises must not have been started.
5. The module M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) must not have been started.

**Competence Goal**
The student is introduced to the basic concepts of Relativistic Quantum Field Theory, masters the relevant theoretical concepts and can apply the computational methods. The student applies his/her knowledge to physical problems and can calculate simple processes of QED. The students deepen their knowledge in the exercises coordinated with the lecture.

**Content**
Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

**Workload**
360 h consisting of attendance time (90 h), wrap-up of the lecture and working on the exercises (270 h)

**Recommendation**
Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

**Literature**
- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory.
- L. Ryder, Quantum Field Theory
4.212 Module: Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises [M-PHYS-102035]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Required Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

**Credits** 8  
**Grading scale** Grade to a tenth  
**Recurrence** Each winter term  
**Duration** 1 term  
**Language** English  
**Level** 4  
**Version** 1

| Mandatory |  
| T-PHYS-102546 | Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises | 8 CR | Heinrich, Melnikov, Mühlleitner, Nierste, Steinhauser |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises must not have been started.  
2. The module M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises must not have been started.  
3. The module M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises must not have been started.  
4. The module M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) must not have been started.  
5. The module M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) must not have been started.

**Competence Goal**  
The student is introduced to the basic concepts of Relativistic Quantum Field Theory, masters the relevant theoretical concepts and can apply the computational methods. The student applies his/her knowledge to physical problems and can calculate simple processes of QED.

**Content**  
Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

**Workload**  
240 h consisting of attendance time (60 h), wrap-up of lecture incl. exam preparation (180 h)

**Recommendation**  
Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

**Literature**  
- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory.  
- L. Ryder, Quantum Field Theory
Module: Theoretical Particle Physics I, Fundamentals, with Exercises [M-PHYS-102034]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Required Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises must not have been started.
2. The module M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises must not have been started.
3. The module M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises must not have been started.
4. The module M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) must not have been started.
5. The module M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) must not have been started.

**Competence Goal**  
The student is introduced to the basic concepts of Relativistic Quantum Field Theory, masters the relevant theoretical concepts and can apply the computational methods. The students deepen their knowledge in the exercises coordinated with the lecture.

**Content**  
Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

**Workload**  
240 h consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and working on the exercises (180 h)

**Recommendation**  
Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

**Literature**

- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory  
- L. Ryder, Quantum Field Theory
Module: Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) [M-PHYS-102038]

Responsible: Prof. Dr. Gudrun Heinrich
Prof. Dr. Kirill Melnikov
Prof. Dr. Milada Margarete Mühlleitner
Prof. Dr. Ulrich Nierste
Prof. Dr. Matthias Steinhauser

Organisation: KIT Department of Physics
Part of: Minor in Physics: Theoretical Particle Physics

Credits 8
Grading scale pass/fail
Recurrence Each winter term
Duration 1 term
Language English
Level 4
Version 1

Mandatory

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Competence Certificate
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

Prerequisites
none

Modeled Conditions
The following conditions have to be fulfilled:

1. The module M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises must not have been started.
2. The module M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises must not have been started.
3. The module M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises must not have been started.
4. The module M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises must not have been started.
5. The module M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) must not have been started.

Competence Goal
The student is introduced to the basic concepts of Relativistic Quantum Field Theory, masters the relevant theoretical concepts and can apply the computational methods. The students deepen their knowledge in the exercises coordinated with the lecture.

Content
Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

Workload
240 h consisting of attendance time (60 h), wrap-up of the lecture and working on the exercises (180 h)

Recommendation
Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

Literature
- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory
- L. Ryder, Quantum Field Theory
4.215 Module: Theoretical Particle Physics I, Fundamentals, without Exercises [M-PHYS-102036]

**Responsible:** Prof. Dr. Gudrun Heinrich
Prof. Dr. Kirill Melnikov
Prof. Dr. Milada Margarete Mühlleitner
Prof. Dr. Ulrich Nierste
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** Second Major in Physics: Theoretical Particle Physics

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises must not have been started.
2. The module M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises must not have been started.
3. The module M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises must not have been started.
4. The module M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) must not have been started.
5. The module M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) must not have been started.

**Competence Goal**

The student will be introduced to the basic concepts of Relativistic Quantum Field Theory, master the relevant theoretical concepts, and be able to apply the computational methods.

**Content**

Classical field theory; Canonical quantization of boson, fermion and vector fields; Perturbation theory, Green's functions and Feynman diagrams; Calculation of effective cross sections; Quantum electrodynamics as gauge theory; Spontaneous symmetry breaking.

**Workload**

180 h consisting of attendance time (45 h), wrap-up of lecture incl. exam preparation (135 h)

**Recommendation**

Basic knowledge of electrodynamics, quantum mechanics and relativity (to the extent of Theory E).

**Literature**

- M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory
- L. Ryder, Quantum Field Theory
Module: Theoretical Particle Physics II, with Exercises [M-PHYS-102046]

**Responsibility:**
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner

**Organisation:**  
KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102044 - Theoretical Particle Physics II, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102048 - Theoretical Particle Physics II, without Exercises must not have been started.

**Competence Goal**

Students know the basic concepts of non-Abelian gauge theories and their application in particle physics. They understand the underlying theoretical concepts and their interrelationships. The students know the standard model of particle physics and can handle the relevant computational methods. The students solve concrete problems of theoretical particle physics using the factual knowledge conveyed in the lecture.

**Content**

In the main part of the lecture, non-Abelian gauge theories and their application in elementary particle physics are discussed. The subject area includes the Lagrangian densities of QCD and the electroweak Standard Model as well as the Higgs mechanism. The Feynman rules that follow from the Lagrangian densities are introduced and applied in perturbation-theoretic calculations of rates for processes involving quarks and gluons. Regularization and renormalization of ultraviolet divergences are also treated, as well as applications of the renormalization group, the QCD beta function, and asymptotic freedom. Infrared divergences, parton distribution functions, and splitting functions are introduced.

**Workload**

360 hours consisting of attendance time (90 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (270 hours)

**Recommendation**

Theoretical Particle Physics I
Module: Theoretical Particle Physics II, with Exercises (Minor) [M-PHYS-102044]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Theoretical Particle Physics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102046 - Theoretical Particle Physics II, with Exercises must not have been started.
2. The module M-PHYS-102048 - Theoretical Particle Physics II, without Exercises must not have been started.

**Competence Goal**
The students know the basic concepts of non-Abelian gauge theories and their application in particle physics. They understand the underlying theoretical concepts and their interrelationships. The students know the standard model of particle physics and can handle the relevant computational methods. The students solve concrete problems of theoretical particle physics using the factual knowledge conveyed in the lecture.

**Content**
In the main part of the lecture, non-Abelian gauge theories and their application in elementary particle physics are discussed. The subject area includes the Lagrangian densities of QCD and the electroweak Standard Model as well as the Higgs mechanism. The Feynman rules that follow from the Lagrangian densities are introduced and applied in perturbation-theoretic calculations of rates for processes involving quarks and gluons. Regularization and renormalization of ultraviolet divergences are also treated, as well as applications of the renormalization group, the QCD beta function, and asymptotic freedom. Infrared divergences, parton distribution functions, and splitting functions are introduced.

**Workload**
360 hours consisting of attendance time (90 hours), wrap-up of the lecture and preparation of the exercises (270 hours).

**Recommendation**
Theoretical Particle Physics I
4.218 Module: Theoretical Particle Physics II, without Exercises [M-PHYS-102048]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Theoretical Particle Physics (Elective Theoretical Particle Physics)  
Second Major in Physics: Theoretical Particle Physics

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**Mandatory**

| T-PHYS-102554 | Theoretical Particle Physics II, without Exercises | 8 CR | Heinrich, Melnikov, Mühlleitner |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-102044 - Theoretical Particle Physics II, with Exercises (Minor) must not have been started.
2. The module M-PHYS-102046 - Theoretical Particle Physics II, with Exercises must not have been started.

**Competence Goal**

The students know the basic concepts of non-Abelian gauge theories and their application in particle physics. They understand the underlying theoretical concepts and their interrelationships. The students know the standard model of particle physics and can handle the relevant calculation methods.

**Content**

In the main part of the lecture, non-Abelian gauge theories and their application in elementary particle physics are discussed. The subject area includes the Lagrangian densities of QCD and the electroweak Standard Model as well as the Higgs mechanism. The Feynman rules that follow from the Lagrangian densities are introduced and applied in perturbation-theoretic calculations of rates for processes involving quarks and gluons. Regularization and renormalization of ultraviolet divergences are also treated, as well as applications of the renormalization group, the QCD beta function, and asymptotic freedom. Infrared divergences, parton distribution functions, and splitting functions are introduced.

**Workload**

240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation (180 hours)

**Recommendation**

Theoretical Particle Physics I
Module: Theoretical Quantum Optics [M-PHYS-105094]

Responsible: Prof. Dr. Anja Metelmann
Prof. Dr. Carsten Rockstuhl

Organisation: KIT Department of Physics

Part of:
- Major in Physics: Nanophysics (Elective Nanophysics)
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
- Second Major in Physics: Nanophysics (Elective Nanophysics)
- Second Major in Physics: Optics and Photonics
- Second Major in Physics: Condensed Matter Theory

Credits 6
Grading scale Grade to a tenth
Recurrence Irregular
Duration 1 term
Language English
Level 4
Version 1

Mandatory
T-PHYS-110303 Theoretical Quantum Optics 6 CR Metelmann, Rockstuhl

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites
none

Competence Goal
The students of quantum optics comprehend the physics of quantum optical phenomena, the necessary theoretical means for their description, and the application of quantum optical resources in different applications and technologies. They learn how to express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum optical phenomena in specific situations. They are trained to solve basic problems in quantum optics.

The students
- learn about the quantisation of electromagnetic fields,
- understands the details of different quantum states of light,
- get an overview over experiments that were important in the development of quantum optics,
- develop an understanding for the quantum optical description of the first and second order coherence functions, and
- understand and can routinely apply different means to describe the interaction of quantum states of light with quantum emitters.

Content
- Quantization of the electromagnetic field
- Various quantum states of light fields: optical photon-number, coherent, squeezed, Schrödinger's cat states
- Classical and quantum coherence theory: photon bunching and antibunching
- Quantum description of optical interferometry: Mach-Zehnder interferometer with photons
- General description of open quantum system: master equation, Heisenberg-Langevin, and stochastic approaches
- Optical test of quantum mechanics: Hong-Ou-Mandel, quantum eraser, and Bell's theorem experiments
- Interaction of a single atom with a classical field and quantum field
- From Rabi model to Jaynes-Cummings model: the most simplest model to describe the light-matter interaction
- Quantum master equation approach: description of finite life time of atoms
- Weak and strong couplings (spontaneous emission, Purcell effect, resonance fluorescence, lasers, and Rabi oscillation)
- Interaction of an ensemble of atoms with a quantum field (Dicke and Tavis-Cummings models, and superradiance)
- Quantum optical applications (quantum cryptography, quantum teleportation, quantum metrology, etc.)

Workload
180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (135 hours).
Recommendation
Interest in theoretical physics, good knowledge in quantum mechanics and electrodynamics/optics

Literature
- C. Gerry and P. Knight, *Introductory Quantum Optics*.
- M. O. Scully and M. S. Zubairy, *Quantum Optics*.
- M. Fox, *Quantum Optics: An Introduction*.
- D.F. Walls and G. J. Milburn, *Quantum Optics*.
- W. Schleich, *Quantum Optics in Phase Space*. 
Module: Theoretical Quantum Optics (Minor) [M-PHYS-105395]

**Responsible:** Prof. Dr. Anja Metelmann
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Nanophysics
- Minor in Physics: Optics and Photonics
- Minor in Physics: Condensed Matter Theory

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-105094 - Theoretical Quantum Optics must not have been started.

**Competence Goal**
The students of quantum optics comprehend the physics of quantum optical phenomena, the necessary theoretical means for their description, and the application of quantum optical resources in different applications and technologies. They learn how to express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum optical phenomena in specific situations. They are trained to solve basic problems in quantum optics.

The students

- learn about the quantisation of electromagnetic fields,
- understand the details of different quantum states of light,
- get an overview over experiments that were important in the development of quantum optics,
- develop an understanding for the quantum optical description of the first and second order coherence functions, and
- understand and can routinely apply different means to describe the interaction of quantum states of light with quantum emitters.

**Content**

- Quantization of the electromagnetic field
- Various quantum states of light fields: optical photon-number, coherent, squeezed, Schrödinger’s cat states
- Classical and quantum coherence theory: photon bunching and antibunching
- Quantum description of optical interferometry: Mach-Zehnder interferometer with photons
- General description of open quantum system: master equation, Heisenberg-Langevin, and stochastic approaches
- Optical test of quantum mechanics: Hong-Ou-Mandel, quantum eraser, and Bell’s theorem experiments
- Interaction of a single atom with a classical field and quantum field
- From Rabi model to Jaynes-Cummings model: the most simplest model to describe the light-matter interaction
- Quantum master equation approach: description of finite life time of atoms
- Weak and strong couplings (spontaneous emission, Purcell effect, resonance fluorescence, lasers, and Rabi oscillation)
- Interaction of an ensemble of atoms with a quantum field (Dicke and Tavis-Cummings models, and superradiance)
- Quantum optical applications (quantum cryptography, quantum teleportation, quantum metrology, etc.)

**Workload**

180 hours consisting of attendance time (45 hours), wrap-up of lecture and completion of exercises (135 hours).
Recommendation
Interest in theoretical physics, good knowledge in quantum mechanics and electrodynamics/optics

Literature

- C. Gerry and P. Knight, *Introductory Quantum Optics*.
- M. O. Scully and M. S. Zubairy, *Quantum Optics*.
- M. Fox, *Quantum Optics: An Introduction*.
- D.F. Walls and G. J. Milburn, *Quantum Optics*.
- W. Schleich, *Quantum Optics in Phase Space*. 
4.221 Module: Theory and Applications of Quantum Machines [M-PHYS-105942]

**Mandatory**

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| CR   | T-PHYS-112018 | Theory and Applications of Quantum Machines | 8 CR | Metelmann |

**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

The students know the possible applications of quantum technologies and understand the operation of key core architectures such as superconducting circuits. Students understand the detrimental effect of dissipation on the operation and performance of quantum technologies, and they learn possible protocols to avoid dissipation. Students learn about various readout elements and protocols and understand the fundamental quantum mechanical limitations of measurements. Students understand the relevant basic concepts in the field of superconducting circuits, such as cavity, qubit, dispersive readout, fidelity, etc., as well as the basic concepts of optomechanical architectures, such as sidebands, dynamic feedback, fundamental limits on measurement accuracy, etc. Students are able to analyze, structure, and formally describe simple problems in the area of open quantum systems. Simple problems here include a two-level system or a mechanical mode coupled to the light field of a cavity. Students are able to apply the methodology of the Heisenberg-Langevin equations as well as that of the master equation. Students are able to perform the calculation of noise spectra of these example systems. Students will learn the modern methodologies of modeling open quantum systems, e.g. the formalism of quantum trajectories, feedback protocols and quasi-distributions.

**Content**

This module aims to provide students with the theoretical and practical aspects of modern quantum technologies. Different technological architectures will be covered, e.g. superconducting circuits as a basis for future efficient computers, optomechanical systems as a basis for increasing the sensitivity of force sensors, or spin-based quantum communication systems. The module will cover the basic concepts of theoretical modeling of open quantum systems, with a focus on quantum mechanical measurement and readout. The influence of dissipation as well as the fundamental limits of measurement accuracy will be addressed. The module will provide an overview of future applications of quantum technologies, and at the same time highlight the challenges that these technologies face.

**Workload**

240 hours consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 h)

**Literature**

1. Quantum Measurement and Control, Howard M. Wiseman und Gerard J. Milburn, Cambridge University Press,
2. Statistical Methods in Quantum Optics 1&2, Howard J. Carmichael, Springer,
4.222 Module: Theory and Applications of Quantum Machines (Minor) [M-PHYS-105943]

**Responsible:** Prof. Dr. Anja Metelmann  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Condensed Matter Theory

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**Competence Certificate**  
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Competence Goal**  
The Students know the possible applications of quantum technologies and understand the operation of key core architectures such as superconducting circuits. Students understand the detrimental effect of dissipation on the operation and performance of quantum technologies, and they learn possible protocols to avoid dissipation. Students learn about various readout elements and protocols and understand the fundamental quantum mechanical limitations of measurements. Students understand the relevant basic concepts in the field of superconducting circuits, such as cavity, qubit, dispersive readout, fidelity, etc., as well as the basic concepts of optomechanical architectures, such as sidebands, dynamic feedback, fundamental limits on measurement accuracy, etc. Students are able to analyze, structure, and formally describe simple problems in the area of open quantum systems. Simple problems here include a two-level system or a mechanical mode coupled to the light field of a cavity. Students are able to apply the methodology of the Heisenberg-Langevin equations as well as that of the master equation. Students are able to perform the calculation of noise spectra of these example systems. Students will learn the modern methodologies of modeling open quantum systems, e.g. the formalism of quantum trajectories, feedback protocols and quasi-distributions.

**Content**  
This module aims to provide students with the theoretical and practical aspects of modern quantum technologies. Different technological architectures will be covered, e.g. superconducting circuits as a basis for future efficient computers, optomechanical systems as a basis for increasing the sensitivity of force sensors, or spin-based quantum communication systems. The module will cover the basic concepts of theoretical modeling of open quantum systems, with a focus on quantum mechanical measurement and readout. The influence of dissipation as well as the fundamental limits of measurement accuracy will be addressed. The module will provide an overview of future applications of quantum technologies, and at the same time highlight the challenges that these technologies face.

**Workload**  
240 hours consisting of attendance time (60 h), wrap-up of the lecture and preparation of the exercises (180 h).

**Literature**

1. Quantum Measurement and Control, Howard M. Wiseman and Gerard J. Milburn, Cambridge University Press,
2. Statistical Methods in Quantum Optics 1 & 2, Howard J. Carmichael, Springer,
4.223 Module: Theory of Magnetism II [M-PHYS-102985]

**Responsible:**  
PD Dr. Igor Gornyi  
PD Dr. Boris Narozhnny

**Organisation:**  
KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)  
Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**

none

**Competence Goal**

Gain knowledge of the fundamentals of the theory of magnetism. Mastering different methods of describing classical and quantum magnets. Acquire physical understanding of the main phenomena and concepts.

**Content**

Anticipated structure of the lecture:

- Introduction
- Molecular field theory for magnets.
- Mott insulators
- Heisenberg magnets.
- Magnetism due to nonlocalized electrons.
- Magnetism and spin transport (giant magnetoresistance, spin-torque effects).
- Spin Hall effect and quantum spin Hall effect.
- Spin fluids.
- Frustrated magnets
- Spin glass

**Workload**

240 h consisting of attendance time (60 h) and wrap-up of the lecture incl. exam preparation (180 h)

**Recommendation**

As a general rule, this lecture should be taken after Condensed Matter Theory I.

**Literature**

4.224 Module: Theory of Magnetism, with Exercises [M-PHYS-105381]

**Responsible:** Prof. Dr. Markus Garst  
**Organisation:** KIT Department of Physics  
**Part of:**  
- Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)  
- Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**
Gaining understanding of phenomena and concepts in quantum and classical magnetism, mastering basic theoretical tools for their description, and acquiring the ability to analyse and solve problems theoretically in the field of magnetism.

**Content**
Introduction to the concepts of magnetism; Heisenberg model; Spin representations; Ground states and excitations; Spin-ice and spin-liquids; Spin path integral and semiclassical approximations; Spin wave theory; Non-linear sigma model and micromagnetism; Landau-Lifshitz-Gilbert equation and conserved quantities; Topological solutions: domain walls, vortices & skyrmions; Spintronics

**Workload**
240 h consisting of attendance time (60 h), wrap-up of the lecture incl. exam preparation and working on the exercises (180 h)

**Recommendation**
Basic knowledge in solid state physics, quantum mechanics, and statistical physics is required.
4.225 Module: Theory of Magnetism, with Exercises (Minor) [M-PHYS-105385]

**Responsible:** Prof. Dr. Markus Garst  
**Organisation:** KIT Department of Physics  
**Part of:** Minor in Physics: Condensed Matter Theory

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Competence Goal**
Gaining understanding of phenomena and concepts in quantum and classical magnetism, mastering basic theoretical tools for their description, and acquiring the ability to analyse and solve problems theoretically in the field of magnetism

**Content**
Introduction to the concepts of magnetism; Heisenberg model; Spin representations; Ground states and excitations; Spin-ice and spin-liquids; Spin path integral and semiclassical approximations; Spin wave theory; Non-linear sigma model and micromagnetism; Landau-Lifshitz-Gilbert equation and conserved quantities; Topological solutions: domain walls, vortices & skyrmions; Spintronics

**Workload**
240 h consisting of attendance time (60 h), follow-up of the lecture and working on the exercises (180 h)

**Recommendation**
Basic knowledge in solid state physics, quantum mechanics, and statistical physics is required.
**4.226 Module: Theory of Seismic Waves [M-PHYS-102367]**

**Responsible:** Prof. Dr. Thomas Bohlen  
**Organisation:** KIT Department of Physics  
**Part of:** Second Major in Physics: Geophysics

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**Credits:** 6  
**Grading scale:** Grade to a tenth  
**Recurrence:** Each summer term  
**Duration:** 1 term  
**Language:** English  
**Level:** 4  
**Version:** 2

**Mandatory**

| T-PHYS-104736 | Theory of Seismic Waves | 6 CR | Bohlen |

**Competence Certificate**
To pass the module, an oral exam must be passed (approx. 20 min). As prerequisites the examinations of other type must be passed, based on successful participation of the exercises. Each exercise deals with a specific topic (e.g., stress and strain tensors, Zoeppritz equations, or rays) and is based on solving a given theoretical problem by means of calculus. In some cases equations and solutions need to be visualized using Matlab (or equivalent tools).

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102657 - Theory of Seismic Waves (Minor) must not have been started.

**Competence Goal**
The students know the fundamental laws and equations of linear elasticity and wave propagation. They understand wave propagation phenomena such as source effects, reflection and transmission or the effects of anisotropy, absorption, dispersion and scattering and can describe them in mathematical terms. They are able to apply the concepts and equations to theoretical problems and relate the theory to phenomena observed in field data.

**Content**
- Theory of elasticity, stress and strain, elastic tensor, fundamental laws and equations  
- Anisotropic elastic wave equation and various simplifications  
- Mathematical description of sources, near-field and far-field terms  
- Boundary conditions  
- Reflection and transmission of plane waves at plane interfaces, Zoeppritz equations  
- Surface waves, dispersion relation, phase and group velocity  
- Introduction to ray theory, eikonal and transport equations and their solutions  
- Absorption and dispersion  
- Wave propagation in anisotropic media  
- Scattering

**Workload**
180 hours composed of attendance time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**
Knowledge of differential and vector calculus is essential. Familiarity with Matlab (alternatively Python or Mathematica) is beneficial for certain exercises.

**Literature**
4.227 Module: Theory of Seismic Waves (Minor) [M-PHYS-102657]

**Responsible:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** Minor in Physics: Geophysics

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**Competence Certificate**
To pass the module, the examinations of other type must be passed, based on successful participation of the exercises. Each exercise deals with a specific topic (e.g., stress and strain tensors, Zoeppritz equations, or rays) and is based on solving a given theoretical problem by means of calculus. In some cases equations and solutions need to be visualized using Matlab (or equivalent tools).

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-102367 - Theory of Seismic Waves must not have been started.

**Competence Goal**
The students know the fundamental laws and equations of linear elasticity and wave propagation. They understand wave propagation phenomena such as source effects, reflection and transmission or the effects of anisotropy, absorption, dispersion and scattering and can describe them in mathematical terms. They are able to apply the concepts and equations to theoretical problems and relate the theory to phenomena observed in field data.

**Content**
- Theory of elasticity, stress and strain, elastic tensor, fundamental laws and equations
- Anisotropic elastic wave equation and various simplifications
- Mathematical description of sources, near-field and far-field terms
- Boundary conditions
- Reflection and transmission of plane waves at plane interfaces, Zoeppritz equations
- Surface waves, dispersion relation, phase and group velocity
- Introduction to ray theory, eikonal and transport equations and their solutions
- Absorption and dispersion
- Wave propagation in anisotropic media
- Scattering

**Workload**
180 hours composed of attendance time (45 h), wrap-up of the lectures and solving the exercises (135 h)

**Recommendation**
Knowledge of differential and vector calculus is essential. Familiarity with Matlab (alternatively Python or Mathematica) is beneficial for certain exercises.

**Literature**
Module: Theory of Strongly Correlated Electron Systems [M-PHYS-106056]

**M.228 Module: Theory of Strongly Correlated Electron Systems [M-PHYS-106056]**

**Responsible:** PD Dr. Robert Eder  
**Organisation:** KIT Department of Physics  
**Part of:** Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**

The students acquire knowledge about strongly correlated electron systems and understand their basic principles, both on the level of atomic physics for realistic models and on the level of simplified models which are deduced from realistic models and used to discuss various effects in actual solids. The students can apply simple theoretical tools such as variational wave functions, canonical transformations, perturbation theory and Green's functions (the latter only on a very basic level). The students also learn and understand applications of the theory to some important experimental techniques in the field such as photoelectron spectroscopy, X-ray absorption spectroscopy and other types of spectroscopy.

**Content**

The module is concerned with the theory of strongly correlated electron systems i.e. solids which contain 3d or 4f transition metal ions. The small radius of the 3d or 4f shells in these elements enhances the Coulomb repulsion between electrons considerably so that one faces a situation where the interaction between particles is the dominant term in the Hamiltonian. The standard theory for electrons in solids therefore loses its validity and a variety of unexpected phenomena are observed. There is no such thing as a universal theory for strongly correlated electron systems, rather there is a variety of theories for approximations to treat different phenomena. The following topics will be addressed: The method of linear combination of atomic orbitals, Coulomb repulsion in atomic shells aka multiplet theory, crystalline electric field effects, Hubbard model and 'classic' approximations, Mott insulators, magnetic exchange and magnetic anisotropy, quantum spin systems, Anderson model and 'classic' approximations, Kondo effect.

**Workload**

360 hours consisting of attendance time (90 h), wrap-up of the lecture incl. exam preparation and preparation of the exercises (270 h)

**Recommendation**

Good knowledge of quantum mechanics and statistical physics and basic knowledge of solid state physics is necessary.

**Literature**

Will be discussed in the lecture.

 Responsible: PD Dr. Igor Gornyi
  Prof. Dr. Alexander Mirlin

 Organisation: KIT Department of Physics

 Part of: Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
  Second Major in Physics: Condensed Matter Theory

 Credits 8
 Grading scale Grade to a tenth
 Recurrence Irregular
 Duration 1 term
 Language English
 Level 4
 Version 1

| Mandatory | T-PHYS-113258 | Topology in Condensed Matter Physics: Fundamentals and Advanced Topics | 8 CR | Gornyi, Mirlin |

 Competence Certificate
 Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

 Modeled Conditions
 The following conditions have to be fulfilled:

 1. The module M-PHYS-106587 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics (Minor) must not have been started.
 2. The module M-PHYS-106588 - Topology in Condensed Matter Physics: Fundamentals and Selected Topics must not have been started.

 Competence Goal
 Gaining understanding of basic concepts of topology in physics and of their applications to modern topics in condensed-matter physics. Mastering theoretical tools for description of topological phenomena in condensed matter physics and acquiring an ability to apply these tools to a solution of a broad class of topology-related problems.

 Content
 From elementary quantum mechanics lectures, we know that different states can be distinguished by their quantum numbers, such as momentum, angular momentum, etc. The appearance of these quantum numbers is closely related to symmetry-related invariance under transformations, e.g., translations or rotations. The introduction of concepts of topology into physics makes it possible to identify further, so-called “topological” quantum numbers. Topological aspects have long been known in physics, e.g., from the Dirac hypothesis of the existence of magnetic monopoles (which would explain the quantization of the electric charge), as well as from nuclear physics of the 50s (“Skyrmions”). The enormous variety of topological effects and their fundamental importance in condensed-matter physics has only become apparent in recent times. Today, an outstanding precision of the integer quantum Hall effect (QHE) is understood as a consequence of its topological nature. Furthermore, extraordinary properties of graphene and of other novel materials—topological insulators and superconductors, Weyl semimetals, etc.—are also due to their topological nature. Fractional charges and exotic statistics of low-lying excitations in fractional QHE are topologically imposed and stabilized, as is also the case for quantum spin liquids. Realizations of Majorana excitations in topological systems are of great interest, especially in connection with their potential application for topological quantum computing. Modern solid-state physics would be deprived of many of its most fascinating and intrinsic aspects without topological concepts.

 The following topics will be covered in the lecture course:

 1. Fundamental topological concepts: winding numbers and homotopy groups, Berry connection, curvature, and phase; Chern numbers; topological (Thouless) pumping.
 2. Models of 1D topological matter: Su–Schrieffer–Heeger model; Kitaev chain with Majorana edge states (1D topological superconductor); Haldane quantum spin chains.
 5. Topological insulators and superconductors, Quantum Spin Hall Effect.
 6. Classification of topological quantum matter; “periodic table” of topological insulators and superconductors; bulk-boundary correspondence
 8. Topology in strongly interacting systems. Topologically ordered phases of matter with fractionalized or non-abelian excitations.
Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

Recommendation
In general this lecture should be attended after Theory of Condensed Matter I.

Literature
- D. Thouless, Topological Quantum Numbers in Non-Relativistic Physics
- A. Altland and B. Simons, Condensed Matter Field Theory
- R. Moessner and J. E. Moore, Topological Phases of Matter
- B. A. Bernevig (with T.L. Hughes), Topological Insulators and Topological Superconductors
- Xiao-Gang Wen, Quantum Field Theory of Many-Body Systems
- S. M. Girvin and Kun Yang, Modern Condensed Matter Physics
- Somendra M. Bhattacharjee et al., Topology and Condensed Matter Physics
- Online course on topology in condensed matter: https://topocondmat.org/
  Topological Quantum Matter -- Weizmann online course: https://www.youtube.com/@topologicalquantummatter-w4105

**Responsibility:** PD Dr. Igor Gornyi  
Prof. Dr. Alexander Mirlin

**Organisation:** KIT Department of Physics  
Part of: Minor in Physics: Condensed Matter Theory

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**Competence Certificate**

The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-106586 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-106588 - Topology in Condensed Matter Physics: Fundamentals and Selected Topics must not have been started.

**Competence Goal**

Gaining understanding of basic concepts of topology in physics and of their applications to modern topics in condensed-matter physics. Mastering theoretical tools for description of topological phenomena in condensed matter physics and acquiring an ability to apply these tools to a solution of a broad class of topology-related problems.

**Content**

From elementary quantum mechanics lectures, we know that different states can be distinguished by their quantum numbers, such as momentum, angular momentum, etc. The appearance of these quantum numbers is closely related to symmetry-related invariance under transformations, e.g., translations or rotations. The introduction of concepts of topology into physics makes it possible to identify further, so-called "topological" quantum numbers. Topological aspects have long been known in physics, e.g., from the Dirac hypothesis of the existence of magnetic monopoles (which would explain the quantization of the electric charge), as well as from nuclear physics of the 50s ("Skyrmions"). The enormous variety of topological effects and their fundamental importance in condensed-matter physics has only become apparent in recent times. Today, an outstanding precision of the integer quantum Hall effect (QHE) is understood as a consequence of its topological nature. Furthermore, extraordinary properties of graphene and of other novel materials---topological insulators and superconductors, Weyl semimetals, etc.---are also due to their topological nature. Fractional charges and exotic statistics of low-lying excitations in fractional QHE are topologically imposed and stabilized, as is also the case for quantum spin liquids. Realizations of Majorana excitations in topological systems are of great interest, especially in connection with their potential application for topological quantum computing. Modern solid-state physics would be deprived of many of its most fascinating and intrinsic aspects without topological concepts.

The following topics will be covered in the lecture course:

1. Fundamental topological concepts: winding numbers and homotopy groups, Berry connection, curvature, and phase; Chern numbers; topological (Thouless) pumping.
2. Models of 1D topological matter: Su–Schrieffer–Heeger model; Kitaev chain with Majorana edge states (1D topological superconductor); Haldane quantum spin chains.
5. Topological insulators and superconductors, Quantum Spin Hall Effect.
6. Classification of topological quantum matter; “periodic table” of topological insulators and superconductors; bulk-boundary correspondence.
8. Topology in strongly interacting systems. Topologically ordered phases of matter with fractionalized or non-abelian excitations.
Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture and preparation of the exercises (180 hours).

Recommendation
In general this lecture should be attended after Theory of Condensed Matter I.

Literature
- D. Thouless, Topological Quantum Numbers in Non-Relativistic Physics
- A. Altland and B. Simons, Condensed Matter Field Theory
- R. Moessner and J. E. Moore, Topological Phases of Matter
- B. A. Bernevig (with T.L. Hughes), Topological Insulators and Topological Superconductors
- Xiao-Gang Wen, Quantum Field Theory of Many-Body Systems
- S. M. Girvin and Kun Yang, Modern Condensed Matter Physics
- Somendra M. Bhattacharjee et al., Topology and Condensed Matter Physics
- Online course on topology in condensed matter: https://topocondmat.org/
  Topological Quantum Matter -- Weizmann online course: https://www.youtube.com/@topologicalquantummatter-w4105

**4.231 Module: Topology in Condensed Matter Physics: Fundamentals and Selected Topics [M-PHYS-106588]**

**Responsible:** PD Dr. Igor Gornyi
Prof. Dr. Alexander Mirlin

**Organisation:** KIT Department of Physics

**Part of:** Major in Physics: Condensed Matter Theory (Elective Condensed Matter Theory)
Second Major in Physics: Condensed Matter Theory

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**Competence Certificate**

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Modeled Conditions**

The following conditions have to be fulfilled:

1. The module M-PHYS-106586 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics must not have been started.
2. The module M-PHYS-106587 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics (Minor) must not have been started.

**Competence Goal**

Gaining understanding of basic concepts of topology in physics and of their applications to selected topics in modern condensed-matter physics.

**Content**

From elementary quantum mechanics lectures, we know that different states can be distinguished by their quantum numbers, such as momentum, angular momentum, etc. The appearance of these quantum numbers is closely related to symmetry-related invariance under transformations, e.g., translations or rotations. The introduction of concepts of topology into physics makes it possible to identify further, so-called “topological” quantum numbers. Topological aspects have long been known in physics, e.g., from the Dirac hypothesis of the existence of magnetic monopoles (which would explain the quantization of the electric charge), as well as from nuclear physics of the 50s (“Skyrmions”). The enormous variety of topological effects and their fundamental importance in condensed-matter physics has only become apparent in recent times. Today, an outstanding precision of the integer quantum Hall effect (QHE) is understood as a consequence of its topological nature. Furthermore, extraordinary properties of graphene and of other novel materials---topological insulators and superconductors, Weyl semimetals, etc.---are also due to their topological nature. Fractional charges and exotic statistics of low-lying excitations in fractional QHE are topologically imposed and stabilized, as is also the case for quantum spin liquids. Realizations of Majorana excitations in topological systems are of great interest, especially in connection with their potential application for topological quantum computing. Modern solid-state physics would be deprived of many of its most fascinating and intrinsic aspects without topological concepts.

The following topics will be covered in the lecture course:

1. Fundamental topological concepts: winding numbers and homotopy groups, Berry connection, curvature, and phase; Chern numbers; topological (Thouless) pumping.
2. Models of 1D topological matter: Su–Schrieffer–Heeger model; Kitaev chain with Majorana edge states (1D topological superconductor); Haldane quantum spin chains.

**Workload**

60 hours consisting of attendance time (15 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (45 hours).

**Recommendation**

In general this lecture should be attended after Theory of Condensed Matter I.

Physics Master (Master of Science)
Module Handbook as of 20/09/2023
Literature

- D. Thouless, Topological Quantum Numbers in Non-Relativistic Physics
- A. Altland and B. Simons, Condensed Matter Field Theory
- R. Moessner and J. E. Moore, Topological Phases of Matter
- B. A. Bernevig (with T. L. Hughes), Topological Insulators and Topological Superconductors
- Xiao-Gang Wen, Quantum Field Theory of Many-Body Systems
- S. M. Girvin and Kun Yang, Modern Condensed Matter Physics
- Somendra M. Bhattacharjee et al., Topology and Condensed Matter Physics
- Online course on topology in condensed matter: https://topocondmat.org/
- Topological Quantum Matter -- Weizmann online course: https://www.youtube.com/@topologicalquantummatter-w4105
4.232 Module: Wildcard Non-Physics Elective, Module with 1 Brick [M-PHYS-102091]

**Organisation:**  KIT Department of Physics  
**Part of:**  Non-Physics Elective

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**Prerequisites**

none
**4.233 Module: Wildcard Non-Physics Elective, Module with 2 Bricks [M-PHYS-103129]**

**Organisation:** KIT Department of Physics  
**Part of:** Non-Physics Elective  

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**Prerequisites**

none
4.234 Module: Wildcard Non-Physics Elective, Module with 3 Bricks [M-PHYS-103130]

**Organisation:**  KIT Department of Physics

**Part of:**  Non-Physics Elective

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**Prerequisites**

none
## 4.235 Module: Wildcard Non-Physics Elective, Module with 4 Bricks [M-PHYS-103131]

**Organisation:** KIT Department of Physics  
**Part of:** Non-Physics Elective

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**Prerequisites**

none
4.236 Module: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab [M-PHYS-105555]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:**  
Major in Physics: Condensed Matter (Elective Condensed Matter)  
Major in Physics: Nanophysics (Elective Nanophysics)  
Major in Physics: Optics and Photonics (Elective Optics and Photonics)  
Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
Second Major in Physics: Nanophysics (Elective Nanophysics)  
Second Major in Physics: Optics and Photonics

**Credits:** 8

**Grading scale:** Grade to a tenth

**Recurrence:** Each winter term

**Duration:** 1 term

**Language:** German/English

**Level:** 4

**Version:** 1

**Mandatory**

| T-PHYS-111156 | X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab | 8 CR | Baumbach, Stankov |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-105556 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab must not have been started.
2. The module M-PHYS-105557 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor) must not have been started.

**Competence Goal**  
Students are introduced to the basic concepts of X-ray physics and its applications to characterize the structure and dynamics of crystalline solids and nanostructures as an extension to topics in wave optics, quantum mechanical scattering theory, crystallography and solid state physics. They understand and are able to apply the physical principles of modern X-ray experimental methods in spatial, frequency and momentum spaces at laboratory sources and large-scale facilities (synchrotron radiation sources, free electron lasers). The lecture, exercises and practical courses at the KIT Light Source combine theory, experiments and high-tech instrumentation with state-of-the-art research applications in the nanoscience. The exercises and practical courses enable the students to prepare and perform X-ray experiments at laboratory X-ray sources and at synchrotron radiation beamlines.

**Content**  
Introduction to modern X-ray physics. The lecture bridges the gap from basic physics to modern X-ray methods for students of physics, chemistry, materials science, crystallography & mineralogy, and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray physics, optics and analysis, esp. X-ray scattering, diffraction and spectroscopy.
- Modern instrumentation in the X-ray laboratory and at large-scale facilities (synchrotron radiation sources, free electron lasers).
- Application examples from crystallography and nanoscience.
- The exercises optionally include the possibility of supervised performance of three experiments on state-of-the-art X-ray equipment of the KIT Light Source.
Workload
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation, preparation and follow-up of the exercises and the internship (180 hours).

Recommendation
Fundamentals of classical electrodynamics, optics, quantum mechanics and basic knowledge of solid state physics.

Literature
Module: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor) [M-PHYS-105557]

4.237 Module: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor) [M-PHYS-105557]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:**
- Minor in Physics: Condensed Matter
- Minor in Physics: Nanophysics
- Minor in Physics: Optics and Photonics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Modeled Conditions**
The following conditions have to be fulfilled:

1. The module M-PHYS-105555 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab must not have been started.
2. The module M-PHYS-105556 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab must not have been started.

**Competence Goal**
Students are introduced to the basic concepts of X-ray physics and its applications to characterize the structure and dynamics of crystalline solids and nanostructures as an extension to topics in wave optics, quantum mechanical scattering theory, crystallography and solid state physics. They understand and are able to apply the physical principles of modern X-ray experimental methods in spatial, frequency and momentum spaces at laboratory sources and large-scale facilities (synchrotron radiation sources, free electron lasers). The lecture, exercises and practical courses at the KIT Light Source combine theory, experiments and high-tech instrumentation with state-of-the-art research applications in the nanoscience. The exercises and practical courses enable the students to prepare and perform X-ray experiments at laboratory X-ray sources and at synchrotron radiation beamlines.

**Content**
Introduction to modern X-ray physics. The lecture bridges the gap from basic physics to modern X-ray methods for students of physics, chemistry, materials science, crystallography & mineralogy, and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray physics, optics and analysis, esp. X-ray scattering, diffraction and spectroscopy.
- Modern instrumentation in the X-ray laboratory and at large-scale facilities (synchrotron radiation sources, free electron lasers).
- Application examples from crystallography and nanoscience.
- The exercises optionally include the possibility of supervised performance of three experiments on state-of-the-art X-ray equipment of the KIT Light Source.

**Workload**
240 hours consisting of attendance time (60 hours), follow-up of the lecture, preparation and follow-up of the exercises and the internship (180 hours).
Recommendation
Fundamentals of classical electrodynamics, optics, quantum mechanics and basic knowledge of solid state physics.

Literature

### 4.238 Module: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab [M-PHYS-105556]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:**  
- Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Major in Physics: Nanophysics (Elective Nanophysics)  
- Major in Physics: Optics and Photonics (Elective Optics and Photonics)  
- Second Major in Physics: Condensed Matter (Elective Condensed Matter)  
- Second Major in Physics: Nanophysics (Elective Nanophysics)  
- Second Major in Physics: Optics and Photonics

**Credits** 4

**Grading scale** Grade to a tenth

**Recurrence** Each winter term

**Duration** 1 term

**Language** German/English

**Level** 4

**Version** 1

| Mandatory | T-PHYS-111157 X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab | 4 CR | Baumbach, Stankov |

**Competence Certificate**  
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**  
none

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The module M-PHYS-105555 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab must not have been started.
2. The module M-PHYS-105557 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor) must not have been started.

**Competence Goal**  
Students are introduced to the basic concepts of X-ray physics and their application to characterize the structure and dynamics of crystalline solids and nanostructures as an extension to topics in wave optics, quantum mechanical scattering theory, crystallography and solid state physics. They understand the physical principles of modern X-ray measurement methods imaging in spatial, frequency and momentum spaces at laboratory sources and large-scale facilities (synchrotron radiation sources, free electron lasers) and can apply them.

**Content**  
Introduction to modern X-ray physics. The lecture bridges the gap from basic physics to modern X-ray methods for students of physics, chemistry, materials science, crystallography & mineralogy, and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray physics, optics and analysis, esp. X-ray scattering, diffraction and spectroscopy.
- Modern instrumentation in the X-ray laboratory and at large facilities (synchrotron facilities, free electron lasers).
- Application examples from crystallography and nanosciences.

**Workload**  
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours).

**Recommendation**  
Fundamentals of classical electrodynamics, optics, quantum mechanics and basic knowledge of solid state physics.
Literature

Module: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab [M-PHYS-105558]

Responsible: Prof. Dr. Gerd Tilo Baumbach
Dr. Svetoslav Stankov

Organisation: KIT Department of Physics

Part of: Major in Physics: Optics and Photonics (Elective Optics and Photonics)
Second Major in Physics: Optics and Photonics

Credits 8
Grading scale Grade to a tenth
Recurrence Each summer term
Duration 1 term
Language German/English
Level 4
Version 1

Competence Certificate
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites none

Competence Goal
Students acquire the experimental and theoretical basis for performing data acquisition and interpretation of 2D and 3D X-ray imaging in real and reciprocal space. This includes microscopic absorption and (non-) interferometric phase contrast imaging, diffraction-enhanced imaging, and scattering methods. The lecture makes connections to routine applications of these methods in life sciences and solid state research at the KIT Light Source. Students apply the knowledge gained in the lecture in experimental group work.

Content
The lecture bridges the gap from basic physics to modern X-ray methods for physicists, chemists and materials scientists and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray optics and X-ray analysis, especially computed tomography, X-ray microscopy, diffraction and scattering.
- Modern instrumentation in the X-ray laboratory and at large-scale facilities (synchrotron storage rings, free electron lasers).
- Application examples from crystallography, nanoscience and life science.

Workload
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation, preparation and follow-up of the exercises and the internship (180 hours).

Recommendation
Fundamentals of classical electrodynamics, optics and basic knowledge of solid state physics.

Literature
### Module: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab (Minor) [M-PHYS-105560]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov  

**Organisation:** KIT Department of Physics  

**Part of:** Minor in Physics: Optics and Photonics

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**Competence Certificate**
The course credit is achieved through successful participation in the exercises. The details will be announced in the first lecture or at the first tutorial.

**Prerequisites**
none

**Competence Goal**
Students acquire the experimental and theoretical basis for performing data acquisition and interpretation of 2D and 3D X-ray imaging in real and reciprocal space. This includes microscopic absorption and (non-) interferometric phase contrast imaging, diffraction-enhanced imaging, and scattering methods. The lecture makes connections to routine applications of these methods in life sciences and solid state research at the KIT Light Source. Students apply the knowledge gained in the lecture in experimental group work.

**Content**
The lecture bridges the gap from basic physics to modern X-ray methods for physicists, chemists and materials scientists and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray optics and X-ray analysis, especially computed tomography, X-ray microscopy, diffraction and scattering.
- Modern instrumentation in the X-ray laboratory and at large-scale facilities (synchrotron storage rings, free electron lasers).
- Application examples from crystallography, nanoscience and life science.

**Workload**
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation, preparation and follow-up of the exercises and the internship (180 hours).

**Recommendation**
Fundamentals of classical electrodynamics, optics and basic knowledge of solid state physics.

**Literature**

Module: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, without Exercises and without Lab [M-PHYS-105559]

Responsible: Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

Organisation: KIT Department of Physics
Part of: Major in Physics: Optics and Photonics (Elective Optics and Photonics)  
Second Major in Physics: Optics and Photonics

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Mandatory

T-PHYS-111160  
X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, without Exercises and without Lab  
4 CR  
Baumbach, Stankov

Competence Certificate

Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Prerequisites

none

Competence Goal

Students acquire the experimental and theoretical basis for performing data acquisition and interpretation of 2D and 3D X-ray imaging in real and reciprocal space. This includes microscopic absorption and (non-)interferometric phase contrast imaging, diffraction-enhanced imaging, and scattering methods. The lecture makes connections to routine applications of these methods in life sciences and solid state research at the KIT Light Source.

Content

The lecture bridges the gap from basic physics to modern X-ray methods for physicists, chemists and materials scientists and gives an overview of important current application fields:

- Theoretical and experimental foundations of X-ray optics and X-ray analysis, especially computed tomography, X-ray microscopy, diffraction and scattering.
- Modern instrumentation in the X-ray laboratory and at large-scale physical facilities (synchrotron storage rings, free electron lasers).
- Application examples from crystallography, nanosciences and life sciences.

Workload

120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation (90 hours).

Recommendation

Fundamentals of classical electrodynamics, optics and basic knowledge of solid state physics.

Literature

## 5 Courses

### 5.1 Course: Accelerator Physics, with ext. Exercises [T-PHYS-109904]

**Responsible:** Dr. Axel Bernhard  
Prof. Dr. Anke-Susanne Müller  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-104869 - Accelerator Physics, with ext. Exercises

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**Legend:**  
🖥 Online,  
🧩 Blended (On-Site/Online),  
🗣 On-Site,  
🗙 Cancelled
### 5.2 Course: Accelerator Physics, with ext. exercises (Minor) [T-PHYS-109903]

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**Responsible:**
Dr. Axel Bernhard  
Prof. Dr. Anke-Susanne Müller

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-104870 - Accelerator Physics, with ext. exercises (Minor)

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5.3 Course: Accelerator Physics, without ext. Exercises [T-PHYS-109905]

**Responsible:**
- Dr. Axel Bernhard
- Prof. Dr. Anke-Susanne Müller

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-104871 - Accelerator Physics, without ext. Exercises

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### 5.4 Course: Accelerator Physics, without ext. exercises (Minor) [T-PHYS-109906]

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**Responsible:** Dr. Axel Bernhard  
Prof. Dr. Anke-Susanne Müller

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104872 - Accelerator Physics, without ext. exercises (Minor)

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**Legend:** 🖥 Online, 🎤 Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled
## 5.5 Course: Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training [T-PHYS-112943]

### Responsible:
- Prof. Dr. Gerd Tilo Baumbach
- Prof. Dr. Anke-Susanne Müller
- Dr. Anton Plech
- Dr. Svetoslav Stankov

### Organisation:
KIT Department of Physics

### Part of:
M-PHYS-106399 - Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training

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### Events

| WT 23/24 | 4028101 | Accelerators and Synchrotron Radiation for Materials Research with Tutorials and a Practical Training | 5 SWS | Block / 🗣: Baumbach, Müller, Härer, Plech, Schuh, Stankov |

Legend: 🖥 Online, ☹ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.6 Course: Advanced Numerical Weather Prediction [T-PHYS-111429]

**Responsible:** Prof. Dr. Peter Knippertz  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Events**

| ST 2021 | 4052051 | Advanced Numerical Weather Prediction | 2 SWS | Lecture / 🖥 | Knippertz |
| ST 2021 | 4052052 | Exercises to Advanced Numerical Weather Prediction | 1 SWS | Practice / 🖥 | Knippertz, Burba, Borne |
| ST 2022 | 4052051 | Advanced Numerical Weather Prediction | 2 SWS | Lecture / 🗣 | Knippertz |
| ST 2022 | 4052052 | Exercises to Advanced Numerical Weather Prediction | 1 SWS | Practice / 🗣 | Knippertz, Burba, Borne |
| ST 2023 | 4052051 | Advanced Numerical Weather Prediction | 2 SWS | Lecture / 🗣 | Knippertz |
| ST 2023 | 4052052 | Exercises to Advanced Numerical Weather Prediction | 1 SWS | Practice / 🗣 | Knippertz, Oertel, Pickl |

*Legend: 🖥 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled*

**Competence Certificate**

Students must achieve 50% of the points on the exercise sheets.

**Prerequisites**

None

**Recommendation**

None

**Annotation**

None
5.7 Course: Advanced Physics Laboratory Course [T-PHYS-102479]

**Responsible:**
Dr. Gernot Guigas  
PD Dr. Andreas Naber  
Dr. Christoph Sürgers  
Dr. Joachim Wolf

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-101395 - Advanced Physics Laboratory Course

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Preliminary meeting for the Advanced lab course for Master students

Practical course /

Naber, Guigas, Sürgers, Wolf

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

Prerequisites
none
### 5.8 Course: Advanced Seminar: Accelerators and Detectors - Future Technologies for Research and Medicine [T-PHYS-112801]

| Responsible: | Prof. Dr. Bernhard Holzapfel  
| | Prof. Dr. Ulrich Husemann  
| | Prof. Dr. Anke-Susanne Müller  
| Organisation: | KIT Department of Physics  
| Part of: | M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics  
| | M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics  

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| ST 2023 | 4013214 | Advanced Seminar: Accelerators and Detectors - Future Technologies for Research and Medicine | 2 SWS | Advanced seminar / ☑ | Husemann, Holzapfel, Müller |

Legend: Online, Blended (On-Site/Online), ☑ On-Site, x Cancelled

**Prerequisites**

none
5.9 Course: Advanced Seminar: Advanced Topics in Quantum Field Theory and Physics Beyond the Standard [T-PHYS-111324]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Events**

| ST 2021 | 4013514 | Advanced Seminar: Advanced Topics in Quantum Field Theory and Physics beyond the Standard | 2 SWS | Advanced seminar | Ziegler, Nierste |

**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5.10 Course: Advanced Seminar: Astroparticle Physics [T-PHYS-110293]

**Responsible:**
- Prof. Dr. Guido Drexlin
- Prof. Dr. Ralph Engel
- Prof. Dr. Kathrin Valerius

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics

**Type**
- Completed coursework

**Credits**
- 4

**Grading scale**
- pass/fail

**Version**
- 1

### Events

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<td>Hauptseminar: Astroteilchenphysik</td>
<td>2 SWS</td>
<td>Advanced seminar / 🖥</td>
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**Legend:**
- 🖥 Online
- 🧩 Blended (On-Site/Online)
- 📞 On-Site
- ✗ Cancelled

**Prerequisites**
none
5.11 Course: Advanced Seminar: Astroparticle Physics and Cosmology [T-PHYS-112800]

**Responsible:** Prof. Dr. Guido Drexlin
Prof. Dr. Ralph Engel
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics

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**Events**

| ST 2023 | 4013224 | Hauptseminar: Astroteilchenphysik und Kosmologie | 2 SWS | Advanced seminar / 🗣️ | Drexlin, Engel, Valerius, Hiller |

Legend: 🖥 Online, 🏦 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
5.12 Course: Advanced Seminar: Conformational Dynamics in Biomolecules [T-PHYS-104544]

Responsible: Prof. Dr. Ulrich Nienhaus
Prof. Dr. Wolfgang Wenzel

Organisation: KIT Department of Physics

Part of: M-PHYS-102204 - Advanced Seminar in the Area Nanophysics
M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics
M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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Prerequisites
none
5.13 Course: Advanced Seminar: Experimental and Theoretical Methods in Particle Physics [T-PHYS-106525]

**Responsible:** PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Günter Quast  
Prof. Dr. Dieter Zeppenfeld

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics  
M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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| ST 2021 | 4013644 | Hauptseminar: Experimentelle und Theoretische Methoden der Teilchenphysik | 2 SWS | Advanced seminar / 🖥 | Quast, Heinrich, Gieseke |
| ST 2022 | 4013644 | Hauptseminar: Experimentelle und Theoretische Methoden der Teilchenphysik | 2 SWS | Advanced seminar / 🖥 | Quast, Heinrich, Gieseke |
| ST 2023 | 4013644 | Hauptseminar: Experimentelle und Theoretische Methoden der Teilchenphysik | 2 SWS | Advanced seminar / 🖥 | Ferber, Heinrich, Rabbertz |

Legend: 🖥 Online, osopher Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5.14 Course: Advanced Seminar: Flavor Physics [T-PHYS-112804]

**Responsible:** Dr. Monika Blanke  
TT-Prof. Dr. Felix Kahlhöfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 👤 On-Site, ✗ Cancelled

**Prerequisites**

none
5 COURSES

5.15 Course: Advanced Seminar: General Relativity [T-PHYS-106126]

Responsible: Prof. Dr. Frans Klinkhamer
Organisation: KIT Department of Physics
Part of: M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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Prerequisites
none
5 COURSES

5.16 Course: Advanced Seminar: General Relativity II [T-PHYS-109974]

**Responsible:** Prof. Dr. Frans Klinkhamer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Klinkhamer, Emelyanov**

**Prerequisites**

none

Legend: 🖥 Online, 🙇 Blended (On-Site/Online), 🗽 On-Site, ✗ Cancelled
5.17 Course: Advanced Seminar: Higgs Meets Flavour [T-PHYS-110830]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Milada Margarete Mühlleitner

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Prerequisites**
none
5.18 Course: Advanced Seminar: Hydrodynamics in Classical and Quantum Fluids [T-PHYS-111323]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5 COURSES

5.19 Course: Advanced Seminar: Light-optical Nanoscopy [T-PHYS-104560]

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Prerequisites
none
5.20 Course: Advanced Seminar: Low Energy Particle Physics (Belle II, LUXE) [T-PHYS-111864]

### Responsible:
- Prof. Dr. Torben Ferber
- Dr. Pablo Goldenzweig

### Organisation:
- KIT Department of Physics

### Part of:
- M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics

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Legend: 🖥 Online, 🛠 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

### Prerequisites
- none
5.21 Course: Advanced Seminar: Modern Particle Accelerators and Research with Photons [T-PHYS-106129]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Prof. Dr. Anke-Susanne Müller

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter  
M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics  
M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics

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**Prerequisites**

none
5.22 Course: Advanced Seminar: Nano Optics [T-PHYS-111862]

**Responsible:** PD Dr. Andreas Naber  
Prof. Dr. Carsten Rockstuhl  
Prof. Dr. Martin Wegener

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102204 - Advanced Seminar in the Area Nanophysics  
M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none

**Responsible:** Prof. Dr. Gerd Tilo Baumbach

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter

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Legend: 📐 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, ☑ Cancelled

**Prerequisites**

none
5.24 Course: Advanced Seminar: Optoelectronics - Fundamentals and Devices [T-PHYS-105789]

**Responsible:** PD Dr. Michael Hetterich  
Prof. Dr. Heinz Kalt

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter  
M-PHYS-102204 - Advanced Seminar in the Area Nanophysics  
M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics

### Events

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**Legend:** 🛥️ Online, 🛡️ Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled

**Prerequisites**

none
5.25 Course: Advanced Seminar: Particle Physics [T-PHYS-112235]

**Responsible:** Prof. Dr. Torben Ferber  
Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
5.26 Course: Advanced Seminar: Particle Physics and Experimental Methods [T-PHYS-105791]

**Responsible:**
- Dr. Pablo Goldenzweig
- Prof. Dr. Ulrich Husemann
- Prof. Dr. Anke-Susanne Müller
- Prof. Dr. Thomas Müller
- Prof. Dr. Günter Quast

**Organisation:**
KIT Department of Physics

**Part of:**
- M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**
none
# 5.27 Course: Advanced Seminar: Particle Physics at the Highest Energy at the LHC [T-PHYS-107566]

**Responsible:** Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute  
Prof. Dr. Thomas Müller  
PD Dr. Roger Wolf  

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics

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**Prerequisites**

none

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**Events**

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

---
5.28 Course: Advanced Seminar: Particle Physics beyond the Standard Model [T-PHYS-111863]

**Responsible:** Prof. Dr. Markus Klute  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102206 - Advanced Seminar in the Area Experimental Particle Physics

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**Prerequisites**
none
5.29 Course: Advanced Seminar: Phenomena of the Quantum World [T-PHYS-112802]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Jörg Schmalian  
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗷 On-Site, ✗ Cancelled

**Prerequisites**

none
5.30 Course: Advanced Seminar: Physics Beyond the Standard Model [T-PHYS-111452]

**Responsible:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Events**

| WT 21/22 | 4013514 | Hauptseminar: Physik jenseits des Standardmodells | 2 SWS | Advanced seminar / | Nierste, Blanke |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**

none
5.31 Course: Advanced Seminar: Quantum Mechanics: Selected Chapters [T-PHYS-113133]

**Responsible:** PD Dr. Robert Eder

**Organisation:** KIT Department of Physics

**Part of:**
- M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics
- M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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**Events**

| WT 23/24 | 4013424 | Advanced Seminar: Quantum Mechanics: Selected chapters | 2 SWS | Advanced seminar / 🗣 | Eder |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**

none
5.32 Course: Advanced Seminar: Quantum Optics [T-PHYS-106523]

**Responsible:** Prof. Dr. David Hunger  
PD Dr. Andreas Naber  
Prof. Dr. Carsten Rockstuhl  
Prof. Dr. Martin Wegener

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter  
M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics  
M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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**Events**

| ST 2021 | 4013024 | Hauptseminar: Quantenoptik | 2 SWS | Advanced seminar | Hunger, Rockstuhl, Wegener |

Legend: 🌐 Online, 🧬 Blended (On-Site/Online), 🔴 On-Site, ✗ Cancelled

**Prerequisites**
none
5.33 Course: Advanced Seminar: Quantum Phase Transitions [T-PHYS-111889]

**Responsible:** Prof. Dr. Markus Garst

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**

none
5.34 Course: Advanced Seminar: Recent Experiments in Quantum Physics [T-PHYS-109971]

**Responsible:** Prof. Dr. David Hunger
Prof. Dr. Matthieu Le Tacon
Prof. Dr. Wolfgang Wernsdorfer
PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter
M-PHYS-102204 - Advanced Seminar in the Area Nanophysics

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Legend: 🕵️ Online, 🛢 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
5.35 Course: Advanced Seminar: Special Relativity [T-PHYS-105793]

**Responsible:** Prof. Dr. Frans Klinkhamer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Prerequisites**
none
5.36 Course: Advanced Seminar: Superconductivity - from Basics to Application [T-PHYS-111014]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter  
M-PHYS-102204 - Advanced Seminar in the Area Nanophysics

**Type**  
Completed coursework

**Credits**  
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**Grading scale**  
pass/fail

**Expansion**  
1 terms

**Version**  
1

**Prerequisites**  
none

**Responsible:** TT-Prof. Dr. Felix Kahlhöfer  
Prof. Dr. Milada Margarete Mühlleitner

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Events**

| ST 2023 | 4013624 | Advanced Seminar: The Matter Puzzle - Baryon Asymmetry, Dark Matter and Particle Physics | 2 SWS | Advanced seminar / 🖥 Mühlleitner, Kahlhöfer |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none

**Responsible:**
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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**Events**

| WT 22/23 | 4013414 | Hauptseminar: Topology in Condensed Matter Physics | 2 SWS | Advanced seminar | Gornyi, Mirlin, Narozhnyy |

**Prerequisites**
none
Course: Advanced Seminar: Units of Measurement and Metrology: No Guessing but Precise Measurement! [T-PHYS-111451]

**Responsible:** Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:**
- M-PHYS-102203 - Advanced Seminar in the Area Condensed Matter
- M-PHYS-102205 - Advanced Seminar in the Area Optics and Photonics

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Legend: 🖥 Online, 🌐 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
**Course: Advanced Seminar: Unraveling the Puzzle of Dark Matter [T-PHYS-112236]**

**Responsible:** Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Thomas Schwetz-Mangold

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-102207 - Advanced Seminar in the Area Experimental Astroparticle Physics  
M-PHYS-102208 - Advanced Seminar in the Area Theoretical Particle Physics

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**Prerequisites**

none
5.41 Course: Advanced Seminar: Virtual Design of Materials [T-PHYS-111865]

**Responsible:** Prof. Dr. Wolfgang Wenzel  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-102204 - Advanced Seminar in the Area Nanophysics  
- M-PHYS-102209 - Advanced Seminar in the Area Condensed Matter Theory

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Legend: 🖥 Online, ☩ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.42 Course: Arctic Climate System [T-PHYS-111273]

**Responsible:** Prof. Dr. Björn-Martin Sinnhuber  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

### Competence Certificate
The assessment consists of a coursework according to §4 (3) SPO MSc Meteorology and Climate Physics in the form of a short lecture (approx. 10 minutes) on a topic relevant to the lecture. The detailed conditions will be discussed in the lecture.

### Prerequisites
None

### Annotation
5.43 Course: Array Techniques in Seismology, graded [T-PHYS-112590]

**Responsible:** apl. Prof. Dr. Joachim Ritter

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106196 - Array Techniques in Seismology (Graded)

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**Competence Certificate**
Grading is based on written reports on exercises. A detailed rating scheme is distributed during the first lecture together with information on the required length of the reports and rating criteria.

**Recommendation**
Participants need to know the basics of seismology.
5.44 Course: Astroparticle Physics I [T-PHYS-102432]

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102075 - Astroparticle Physics I

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Legend: 🖥 Online, ☐ Blended (On-Site/Online), 🗣 On-Site, ☑ Cancelled

**Prerequisites**

none
5.45 Course: Astroparticle Physics I (Minor) [T-PHYS-104379]

**Responsible:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102076 - Astroparticle Physics I (Minor)

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**Prerequisites**

none
5.46 Course: Astroparticle Physics II - Cosmic Rays, with ext. Exercises [T-PHYS-105108]

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102525 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises

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**Legend:** 🖥 Online, 🗭 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
## Course: Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor) [T-PHYS-106317]

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-103184 - Astroparticle Physics II - Cosmic Rays, with ext. Exercises (Minor)

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Legend: 🖥 Online, 🌐 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

### Prerequisites

none
# 5.48 Course: Astroparticle Physics II - Cosmic Rays, without ext. Exercises [T-PHYS-102382]

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102078 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises

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Legend: 🖥 Online, 🌀 Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled

## Prerequisites

none
5.49 Course: Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor) [T-PHYS-104380]

**Responsible:** Prof. Dr. Ralph Engel  
Dr. Markus Roth

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102082 - Astroparticle Physics II - Cosmic Rays, without ext. Exercises (Minor)

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### Prerequisites
none
5.50 Course: Astroparticle Physics II - Gamma Rays and Neutrinos [T-PHYS-111343]

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Ralph Engel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105683 - Astroparticle Physics II - Gamma Rays and Neutrinos

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### Prerequisites

none
5.51 Course: Astroparticle Physics II - Gamma Rays and Neutrinos (Minor) [T-PHYS-111344]

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Ralph Engel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105684 - Astroparticle Physics II - Gamma Rays and Neutrinos (Minor)

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| **Responsible:**          | Prof. Dr. Guido Drexlin  
Prof. Dr. Ralph Engel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105684 - Astroparticle Physics II - Gamma Rays and Neutrinos (Minor)

**Events**

| ST 2021  | 4022131 | Astroteilchenphysik II - Gamma Rays and Neutrinos | 2 SWS | Lecture / 🖥 | Engl, Unger |
| ST 2021  | 4022132 | Übungen zu Astroteilchenphysik II - Gamma Rays and Neutrinos | 2 SWS | Practice / 🖥 | Engl, Fitoussi |
| ST 2022  | 4022131 | Astroparticle Physics II - High-energy gamma rays and neutrinos | 2 SWS | Lecture / 🖥 | Engl, Roth |
| ST 2022  | 4022132 | Exercises to Astroparticle Physics II - High-energy gamma rays and neutrinos | 2 SWS | Practice / 🖥 | Engl, Roth |
| ST 2023  | 4022131 | Astroparticle Physics II - Gamma-Ray Astronomy and Neutrinos | 2 SWS | Lecture / 🖥 | Engl, Veberic |
| ST 2023  | 4022132 | Exercises to Astroparticle Physics II - Gamma-Ray Astronomy and Neutrinos | 2 SWS | Practice / 🖥 | Engl, Veberic |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.52 Course: Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises [T-PHYS-111346]

**Responsible:** Prof. Dr. Guido Drexlin  
Pro. Dr. Ralph Engel  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-105686 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
**Course: Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor) [T-PHYS-111345]**

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Ralph Engel  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-105685 - Astroparticle Physics II - Gamma Rays and Neutrinos, with ext. Exercises (Minor)

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Legend: 🖥️ Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
### Course: Astroparticle Physics II - Particles and Stars, with ext. Exercises [T-PHYS-105110]

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**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102527 - Astroparticle Physics II - Particles and Stars, with ext. Exercises

**Type**  
Oral examination

**Credits**  
8

**Grading scale**  
Grade to a third

**Version**  
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**Prerequisites**  
none
### 5.55 Course: Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor) [T-PHYS-106319]

**Responsible:** Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103186 - Astroparticle Physics II - Particles and Stars, with ext. Exercises (Minor)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🔊 On-Site, ✗ Cancelled

**Prerequisites**
none
5.56 Course: Astroparticle Physics II - Particles and Stars, without ext. Exercises [T-PHYS-102498]

Responsibility: Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

Organisation: KIT Department of Physics

Part of: M-PHYS-102081 - Astroparticle Physics II - Particles and Stars, without ext. Exercises

Type: Oral examination
Credits: 6
Grading scale: Grade to a third
Version: 1

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

Prerequisites

none
**5.57 Course: Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor) [T-PHYS-104383]**

**Responsible:**  
Prof. Dr. Guido Drexlin  
Prof. Dr. Kathrin Valerius

**Organisation:**  
KIT Department of Physics

**Part of:**  
M-PHYS-102086 - Astroparticle Physics II - Particles and Stars, without ext. Exercises (Minor)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 📚 On-Site, ✗ Cancelled

**Prerequisites**

none
**5.58 Course: Atmospheric Aerosols [T-PHYS-111418]**

**Responsible:** Dr. Ottmar Möhler  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🧩 On-Site, 🗑 Cancelled

**Competence Certificate**
The students participating in the lecture on Atmospheric Aerosols with Exercises are expected to regularly participate in the Exercises. To pass the course, each student has to submit a solution for at least 50% of all exercises, and to present at least one solution to the tutor and the other participants.

**Prerequisites**
None

**Recommendation**
None

**Annotation**
None
5.59 Course: Atmospheric Radiation [T-PHYS-111419]

**Responsible:** PD Dr. Michael Höpfner

**Organisation:** KIT Department of Physics

**Part of:**
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Competence Certificate**
Short presentation at the end of the semester

**Prerequisites**
None

**Recommendation**
None

**Annotation**
None
5.60 Course: Basics Module - Self Assignment BAK [T-ZAK-112653]

Responsible: Dr. Christine Mielke
Christine Myglas

Organisation:
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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Competence Certificate
The monitoring in this module includes a course credit according to § 5 section 4 in the form of minutes of which two are to be handed in freely chosen topics of the lecture series "Introduction to Applied Studies on Culture and Society". Length: approx. 6,000 characters each (incl. spaces).

Self service assignment of supplementary studies
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

Recommendation

Annotation
The Basic Module consists of the lecture "Introduction to Supplementary Studies on Culture and Society", which is offered only in the winter semester. It is therefore recommended that students start their studies in the winter semester and complete them before module 2.
### Competence Certificate
The monitoring in this module includes a course credit according to § 5 section 4:

- **Introduction to Sustainable Development** in the form of minutes of which two are to be handed in freely chosen topics of the lecture series "Introduction to Sustainable Development". Length: approx. 6,000 characters each (incl. spaces).

- or

- **Sustainability Spring Days at KIT** in the form of a reflection report on all components of the project days “Sustainability Spring Days at KIT”. Length approx. 12,000 characters (incl. spaces).

### Prerequisites
None

### Self service assignment of supplementary studies
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

### Recommendation


### Annotation
Module Basics consists of the lecture " Introduction to Sustainable Development ", which is only offered in the summer semester or alternatively of the project days " Sustainability Spring Days at KIT ", which is only offered in the winter semester. It is recommended to complete the course before Elective Module or Specialisation Module.

In exceptional cases, Elective Module or Specialisation Module can also be completed simultaneously with Basics Module. However, the prior completion of the advanced modules Elective and Specialisation should be avoided.
### 5.62 Course: Basics of Nanotechnology I [T-PHYS-102529]

**Responsible:** apl. Prof. Dr. Gernot Goll  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102097 - Basics of Nanotechnology I

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**  
none
### 5.63 Course: Basics of Nanotechnology I (Minor) [T-PHYS-102528]

**Responsible:** apl. Prof. Dr. Gernot Goll  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102096 - Basics of Nanotechnology I (Minor)

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**Prerequisites**

none
### 5.64 Course: Basics of Nanotechnology II [T-PHYS-102531]

**Responsible:** apl. Prof. Dr. Gernot Goll  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102100 - Basics of Nanotechnology II

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**Prerequisites**  
none
5.65 Course: Basics of Nanotechnology II (Minor) [T-PHYS-102530]

Responsible: apl. Prof. Dr. Gernot Goll
Organisation: KIT Department of Physics
Part of: M-PHYS-102099 - Basics of Nanotechnology II (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

Prerequisites
none
## 5.66 Course: Block Practical Course: ETP Data Science [T-PHYS-113159]

| Responsible          | Prof. Dr. Torben Ferber  
|                      | Dr. rer. nat. Jan Kieseler  
|                      | Prof. Dr. Markus Klute  
| Organisation         | KIT Department of Physics  
| Part of              | M-PHYS-106530 - Block Practical Course: ETP Data Science  

| Type                | Completed coursework  
| Credits             | 2  
| Grading scale       | pass/fail  
| Recurrence          | Each winter term  
| Version             | 1  

### Events

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T 5.67 Course: Classical Theory of Gauge Fields [T-PHYS-111943]

**Responsible:** Prof. Dr. Ulrich Nierste
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105934 - Classical Theory of Gauge Fields

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| ST 2022 | 4026191 | Classical Theory of Gauge Fields | 2 SWS | Lecture / Ziegler, Nierste |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.68 Course: Climate Modeling & Dynamics with ICON [T-PHYS-111412]

**Responsible:** Prof. Dr. Joaquim José Ginete Werner Pinto  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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#### Competence Certificate
Successful participation in the exercises.

#### Prerequisites
None

#### Recommendation
None

#### Annotation
None

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.69 Course: Cloud Physics [T-PHYS-111416]

**Responsible:**  Prof. Dr. Corinna Hoose  
**Organisation:**  KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Legend:**  
- 🖥 Online  
- 💬 Blended (On-Site/Online)  
- 🗣 On-Site  
- ❌ Cancelled

**Competence Certificate**

At least 50% of the points of the exercises have to be reached. At least once, a solution to one of the exercises has to be presented in class.

**Prerequisites**  
None

**Recommendation**  
None

**Annotation**  
None
5.70 Course: Computational Condensed Matter Physics [T-PHYS-109895]

**Responsible:** Prof. Dr. Wolfgang Wenzel  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104862 - Computational Condensed Matter Physics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 💬 On-Site, ❌ Cancelled
## 5.71 Course: Computational Condensed Matter Physics (Minor) [T-PHYS-109894]

**Responsible:** Prof. Dr. Wolfgang Wenzel  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104863 - Computational Condensed Matter Physics (Minor)

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Legend: 🖥️ Online, 💼 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### Course: Computational Methods for Particle Physics and Cosmology [T-PHYS-112378]

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Legend: 🖥 Online, 🐣 Blended (On-Site/Online), 🗂 On-Site, ✗ Cancelled
5.73 Course: Computational Methods for Particle Physics and Cosmology (Minor) [T-PHYS-112379]

**Responsible:** TT-Prof. Dr. Felix Kahlhöfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106118 - Computational Methods for Particle Physics and Cosmology (Minor)

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Legend: 🖥 Online, 🔄 Blended (On-Site/Online), 🗣 On-Site, 🗑 Cancelled
### 5.74 Course: Computational Photonics, with ext. Exercises [T-PHYS-103633]

**Responsible:** Prof. Dr. Carsten Rockstuhl  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-101933 - Computational Photonics, with ext. Exercises

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#### Events

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| ST 2023 | 4023022 | Exercises to Computational Photonics | 1 SWS | Practice / 🗣️ | Rockstuhl, Nyman |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

*none*
5.75 Course: Computational Photonics, with ext. Exercises (Minor) [T-PHYS-106132]

**Responsible:** Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103090 - Computational Photonics, with ext. Exercises (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5.76 Course: Computational Photonics, without ext. Exercises [T-PHYS-106131]

**Responsible:** Prof. Dr. Carsten Rockstuhl  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103089 - Computational Photonics, without ext. Exercises

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.77 Course: Computational Photonics, without ext. Exercises (Minor) [T-PHYS-106326]

Responsible: Prof. Dr. Carsten Rockstuhl
Organisation: KIT Department of Physics
Part of: M-PHYS-103193 - Computational Photonics, without ext. Exercises (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗂 On-Site, ❌ Cancelled

Prerequisites
none
5.78 Course: Condensed Matter Theory I, Fundamentals [T-PHYS-102559]

**Responsible:**
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- Prof. Dr. Alexander Shnirman

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102054 - Condensed Matter Theory I, Fundamentals

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Legend: 📱 Online, 🔄 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
5.79 Course: Condensed Matter Theory I, Fundamentals (Minor) [T-PHYS-102557]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102052 - Condensed Matter Theory I, Fundamentals (Minor)

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**Legend:** 📱 Online, 🎨 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
# 5.80 Course: Condensed Matter Theory I, Fundamentals and Advanced Topics [T-PHYS-102558]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
Prof. Dr. Alexander Shnirman  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics

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Legend: 📚 Online, 🏝 Blended (On-Site/Online), 🗂 On-Site, ❌ Cancelled

**Prerequisites**

none
## 5.81 Course: Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor) [T-PHYS-102556]

**Responsible:**  
Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
Prof. Dr. Alexander Shnirman

**Organisation:**  
KIT Department of Physics

**Part of:**  
M-PHYS-102051 - Condensed Matter Theory I, Fundamentals and Advanced Topics (Minor)

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**Legend:**  
- Online  
- Blended (On-Site/Online)  
- On-Site  
- Cancelled

### Prerequisites

none
### Course: Condensed Matter Theory II: Many-Body Systems, Fundamentals [T-PHYS-104591]

**Responsible:**
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- PD Dr. Boris Narozhnyy
- Prof. Dr. Jörg Schmalian

**Organisation:**
- KIT Department of Mathematics
- KIT Department of Physics

**Part of:**
- M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals

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**Legend:** 📚 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
## 5.83 Course: Condensed Matter Theory II: Many-Body Systems, Fundamentals (Minor) [T-PHYS-104592]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102314 - Condensed Matter Theory II: Many-Body Theory, Fundamentals (Minor)

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| ST 2021 | 4024112 | Exercises to Condensed Matter Theory II | 2 SWS | Practice / 📲 | Garst, Azhar |
| ST 2022 | 4024111 | Condensed Matter Theory II: Many-Body Theory | 4 SWS | Lecture / 📲 | Garst |
| ST 2022 | 4024112 | Exercises to Condensed Matter Theory II | 2 SWS | Practice / 📲 | Garst, Azhar |
| ST 2023 | 4024111 | Condensed Matter Theory II: Many-Body Theory | 4 SWS | Lecture / 📲 | Mirlin, Gornyi |
| ST 2023 | 4024112 | Exercises to Condensed Matter Theory II | 2 SWS | Practice / 📲 | Mirlin, Gornyi, Pöpperl, Ojajärvi |

Legend: 📲 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.84 Course: Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics [T-PHYS-102560]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics

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Legend: 📚 Online, 📖 Blended (On-Site/Online), 🗣 On-Site, ☑ Cancelled
## 5.85 Course: Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics (Minor) [T-PHYS-102562]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Alexander Mirlin  
PD Dr. Boris Narozhnyy  
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102312 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics (Minor)

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**Legend:** 📚 Online, 🕰 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
# 5.86 Course: Condensed Matter Theory II: Many-Body Systems, selected topics [T-PHYS-106676]

**Responsible:**
- Prof. Dr. Markus Garst
- Prof. Dr. Alexander Mirlin
- PD Dr. Boris Narozhnyy
- Prof. Dr. Jörg Schmalian

**Organisation:**
- KIT Department of Physics

**Part of:**
- M-PHYS-103331 - Condensed Matter Theory II: Many-Body Theory, selected topics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
# 5.87 Course: Detectors for Particle and Astroparticle Physics, with ext. Exercises [T-PHYS-102378]

**Responsible:**
- PD Dr. Frank Hartmann
- Prof. Dr. Ulrich Husemann
- Prof. Dr. Markus Klute

**Organisation:**
KIT Department of Physics

**Part of:**
- M-PHYS-102121 - Detectors for Particle and Astroparticle Physics, with ext. Exercises

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**Prerequisites**
none
Course: Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor) [T-PHYS-102431]

**Responsible:** PD Dr. Frank Hartmann  
Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102122 - Detectors for Particle and Astroparticle Physics, with ext. Exercises (Minor)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, △ Cancelled

**Prerequisites**

none
### Course: Detectors for Particle and Astroparticle Physics, without ext. Exercises [T-PHYS-104453]

**Responsible:** PD Dr. Frank Hartmann  
Prof. Dr. Ulrich Husemann  
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102119 - Detectors for Particle and Astroparticle Physics, without ext. Exercises

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**Prerequisites**

none
5 COURSES

Course: Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) [T-PHYS-104454]

5.90 Course: Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor) [T-PHYS-104454]

**Responsible:** PD Dr. Frank Hartmann
Prof. Dr. Ulrich Husemann
Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102120 - Detectors for Particle and Astroparticle Physics, without ext. Exercises (Minor)

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**

none
5.91 Course: Elective Module - Subject, Body, Individual: the Other Side of Sustainability - Self Assignment BeNe [T-ZAK-112349]

Organisation:
Part of: M-ZAK-106099 - Supplementary Studies on Sustainable Development

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Competence Certificate
Examination of another kind according to § 7 section 7 in the form of a presentation in the selected course.

Prerequisites
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

Self service assignment of supplementary studies
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

Recommendation
The content of the Basics Module is helpful.
5.92 Course: Elective Module - Sustainability Assessment of Technology - Self Assignment BeNe [T-ZAK-112348]

Organisation:
Part of: M-ZAK-106099 - Supplementary Studies on Sustainable Development

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Competence Certificate
Examination of another kind according to § 7 section 7 in the form of a presentation in the selected course.

Prerequisites
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

Self service assignment of supplementary studies
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

Recommendation
The content of the Basics Module is helpful.
5.93 Course: Elective Module - Sustainability in Culture, Economy and Society - Self Assignment BeNe [T-ZAK-112350]

Organisation:
Part of: M-ZAK-106099 - Supplementary Studies on Sustainable Development

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**Competence Certificate**
Examination of another kind according to § 7 section 7 in the form of a presentation in the selected course.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary stdues**
This course can be used for self service assignment of grade acquired from the following study providers:
- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Recommendation**
The content of the Basics Module is helpful.
### 5.94 Course: Elective Module - Sustainable Cities and Neighbourhoods - Self Assignment BeNe [T-ZAK-112347]

**Organisation:** University

**Part of:** M-ZAK-106099 - Supplementary Studies on Sustainable Development

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**Competence Certificate**
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**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary stdues**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Recommendation**
The content of the Basics Module is helpful.
5.95 Course: Electron Microscopy I, with Exercises [T-PHYS-105965]

**Responsible:** TT-Prof. Dr. Yolita Eggeler

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102989 - Electron Microscopy I, with Exercises

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**Prerequisites**

none
# 5.96 Course: Electron Microscopy I, with Exercises (Minor) [T-PHYS-105968]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102991 - Electron Microscopy I, with Exercises (Minor)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
5.97 Course: Electron Microscopy I, without Exercises [T-PHYS-105967]

**Responsible:** TT-Prof. Dr. Yolita Eggeler

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102990 - Electron Microscopy I, without Exercises

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**Prerequisites**
none
## Course: Electron Microscopy II, with Exercises [T-PHYS-102349]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102227 - Electron Microscopy II, with Exercises

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**  
none
### Course: Electron Microscopy II, with Exercises (Minor) [T-PHYS-106306]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103172 - Electron Microscopy II, with Exercises (Minor)

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**Prerequisites**

none
### 5.100 Course: Electron Microscopy II, without Exercises [T-PHYS-105817]

**Responsible:** TT-Prof. Dr. Yolita Eggeler  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102844 - Electron Microscopy II, without Exercises

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**Prerequisites**
none
## 5.101 Course: Electronic Properties of Solids I, with Exercises [T-PHYS-102577]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102089 - Electronic Properties of Solids I, with Exercises

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**Prerequisites**

none
Course: Electronic Properties of Solids I, with Exercises (Minor) [T-PHYS-102575]

**Responsible:**  
Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

**Organisation:**  
KIT Department of Physics

**Part of:**  
M-PHYS-102087 - Electronic Properties of Solids I, with Exercises (Minor)

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| WT 22/23   | 4021011 | Electronic Properties of Solids I | 4 SWS | Lecture / 🗣 | Le Tacon, Willke |
| WT 22/23   | 4021012 | Übungen zu Elektronische Eigenschaften von Festkörpern I | 1 SWS | Practice | Le Tacon, Willke |
| WT 23/24   | 4021011 | Electronic Properties of Solids I | 4 SWS | Lecture / 🗣 | Le Tacon, Willke |
| WT 23/24   | 4021012 | Exercises to Electronic Properties of Solids I | 1 SWS | Practice | Le Tacon, Willke |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, x Cancelled

**Prerequisites**

none
5.103 Course: Electronic Properties of Solids I, without Exercises [T-PHYS-102578]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Prof. Dr. Wolfgang Wernsdorfer  
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102090 - Electronic Properties of Solids I, without Exercises

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, 🗐 Cancelled

**Prerequisites**

none
5.104 Course: Electronic Properties of Solids II, with Exercises [T-PHYS-104422]

**Responsible:**
Prof. Dr. Matthieu Le Tacon  
Dr. Johannes Rotzinger  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102108 - Electronic Properties of Solids II, with Exercises

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**Prerequisites**

none
5.105 Course: Electronic Properties of Solids II, with Exercises (Minor) [T-PHYS-104420]

**Responsible:**
- Prof. Dr. Matthieu Le Tacon
- Dr. Johannes Rotzinger
- Prof. Dr. Alexey Ustinov
- Prof. Dr. Wolfgang Wernsdorfer

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102106 - Electronic Properties of Solids II, with Exercises (Minor)

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**Prerequisites**
none
5.106 Course: Electronic Properties of Solids II, without Exercises [T-PHYS-104423]

**Responsible:** Prof. Dr. Matthieu Le Tacon  
Dr. Johannes Rotzinger  
Prof. Dr. Alexey Ustinov  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102109 - Electronic Properties of Solids II, without Exercises

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| ST 2023 | 4021111 | Elektronische Eigenschaften von Festkörpern II | 2 SWS | Lecture / 🗣 | Ustinov |

Legend: 🖥 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**

none
### 5.107 Course: Electronics for Physicists [T-PHYS-104479]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102184 - Electronics for Physicists

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Legend: 🖥 Online, 🟦 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### 5.108 Course: Electronics for Physicists (Minor) [T-PHYS-104480]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon  

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102185 - Electronics for Physicists (Minor)

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**Legend:**  
🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### 5.109 Course: Electronics for Physicists: Analog Electronics [T-PHYS-104475]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102179 - Electronics for Physicists: Analog Electronics

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗾 On-Site, ✗ Cancelled
### 5.110 Course: Electronics for Physicists: Analog Electronics (Minor) [T-PHYS-104476]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102180 - Electronics for Physicists: Analog Electronics (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🔴 On-Site, ✗ Cancelled
### 5.111 Course: Electronics for Physicists: Digital Electronics [T-PHYS-104477]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102182 - Electronics for Physicists: Digital Electronics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### Course: Electronics for Physicists: Digital Electronics (Minor) [T-PHYS-104478]

**Responsible:** PD Dr. Klaus Rabbertz  
Prof. Dr. Frank Simon

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102183 - Electronics for Physicists: Digital Electronics (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
5.113 Course: Energetics [T-PHYS-111417]

**Responsible:** Prof. Dr. Andreas Fink

**Organisation:** KIT Department of Physics

**Part of:**
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Competence Certificate**

Active participation

**Prerequisites**

None

**Recommendation**

None

**Annotation**

None
### 5.114 Course: Energy Meteorology [T-PHYS-111428]

**Responsible:** apl. Prof. Dr. Stefan Emeis  
Prof. Dr. Joaquim José Ginete Werner Pinto

**Organisation:** KIT Department of Physics

**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Events**

| ST 2021 | 4052191 | Energy Meteorology | 2 SWS | Lecture / 🖥️ | Emeis, Schroedter-Homscheidt, Ginete Werner Pinto |
| ST 2022 | 4052191 | Energy Meteorology | 2 SWS | Lecture / 🗣️ | Emeis, Schroedter-Homscheidt, Ginete Werner Pinto |
| ST 2023 | 4052191 | Energy Meteorology | 2 SWS | Lecture / 🗣️ | Emeis, Schroedter-Homscheidt, Ginete Werner Pinto, Grams |

**Legend:** 🖥️ Online, ☐ Blended (On-Site/Online), 🗣️ On-Site, ☑ Cancelled

**Competence Certificate**

The students work in small groups on a task chosen at the beginning of the course on the topics of wind, solar or electricity grids. At the end, each student presents his or her results in a short presentation (max. 5 slides) followed by a discussion.

**Prerequisites**

None

**Recommendation**

None

**Annotation**

None
5.115 Course: Exam on Selected Topics in Meteorology (Second Major) [T-PHYS-109380]

Responsible: Prof. Dr. Corinna Hoose
Organisation: KIT Department of Physics
Part of: M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)

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Competence Certificate
Oral Exam

Prerequisites
Courses of at least 10 CP from the elective options of the module must be part of the oral examination.
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Legend: 🖥️ Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ⌚️ Cancelled
### 5.117 Course: Experimental Biophysics II, with Seminar (Minor) [T-PHYS-102533]

**Responsible:** Prof. Dr. Ulrich Nienhaus  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102166 - Experimental Biophysics II, with Seminar (Minor)

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| ST 2021 | 4020122 | Übungen zu Experimentelle Biophysik II | 2 SWS | Practice / 🖥️ | Nienhaus, Guigas |
| ST 2021 | 4020124 | Seminar zu Experimentelle Biophysik II | 2 SWS | Seminar / 🖥️ | Nienhaus, Guigas |
| ST 2021 | 4020125 | Experimentelle Biophysik IIb | 2 SWS | Lecture / 🖥️ | Nienhaus |
| ST 2022 | 4020121 | Experimentelle Biophysik Ila | 2 SWS | Lecture / 🖥️ | Nienhaus |
| ST 2022 | 4020122 | Übungen zu Experimentelle Biophysik II | 2 SWS | Practice / 🖥️ | Nienhaus, Guigas |
| ST 2022 | 4020124 | Seminar zu Experimentelle Biophysik II | 2 SWS | Seminar / 🖥️ | Nienhaus, Guigas |
| ST 2022 | 4020125 | Experimentelle Biophysik IIb | 2 SWS | Lecture / 🖥️ | Nienhaus |
| ST 2023 | 4020121 | Experimentelle Biophysik Ila | 2 SWS | Lecture / 🖥️ | Nienhaus |
| ST 2023 | 4020122 | Übungen zu Experimentelle Biophysik II | 2 SWS | Practice / 🖥️ | Nienhaus, Guigas |
| ST 2023 | 4020124 | Seminar zu Experimentelle Biophysik II | 2 SWS | Seminar / 🖥️ | Nienhaus, Guigas |
| ST 2023 | 4020125 | Experimentelle Biophysik IIb | 2 SWS | Lecture / 🖥️ | Nienhaus |

**Legend:** 🖥️ Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.118 Course: Experimental Biophysics II, without Seminar [T-PHYS-104471]

**Responsible:** Prof. Dr. Ulrich Nienhaus  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102167 - Experimental Biophysics II, without Seminar

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.119 Course: Experimental Biophysics II, without Seminar (Minor) [T-PHYS-104472]

**Responsible:** Prof. Dr. Ulrich Nienhaus  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102168 - Experimental Biophysics II, without Seminar (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cannedled

#### Prerequisites

none
### 5.120 Course: Field Theories of Condensed Matter: Conformal Field Theory [T-PHYS-109320]

**Responsible:** PD Dr. Igor Gornyi  
PD Dr. Boris Narozhnny

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104548 - Field Theories of Condensed Matter: Conformal Field Theory

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**Events**

| ST 2021 | 4024151 | Field Theories of Condensed Matter: Conformal Field Theory | 3 SWS | Lecture / 📱 | Gornyi, Narozhnny, Snizhko |
| ST 2021 | 4024152 | Exercises to Field Theories of Condensed Matter | 1 SWS | Practice / 📚 | Gornyi, Narozhnny, Snizhko |

Legend: 📱 Online, 🕭 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.121 Course: Flavour Physics in the Standard Model and beyond [T-PHYS-110281]

**Responsible:** Dr. Monika Blanke  
Prof. Dr. Ulrich Nierste  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-105064 - Flavour Physics in the Standard Model and beyond

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**Events**

| ST 2022 | 4026181 | Flavour physics in the Standard Model and beyond | 2 SWS | Lecture / 🗣 | Blanke, Nierste |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.122 Course: Full-Waveform Inversion [T-PHYS-109272]

**Responsible:** Prof. Dr. Thomas Bohlen  
Dr. Thomas Hertweck  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-104522 - Full-Waveform Inversion (Ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), ☑ On-Site, ☒ Cancelled
5.123 Course: General Relativity [T-PHYS-102395]

**Responsible:** Prof. Dr. Frans Klinkhamer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102319 - General Relativity

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**Legend:** 
- Online
- Blended (On-Site/Online)
- On-Site
- Cancelled

**Prerequisites**

none
T 5.124 Course: General Relativity (Minor) [T-PHYS-102446]

Responsible: Prof. Dr. Frans Klinkhamer
Organisation: KIT Department of Physics
Part of: M-PHYS-102320 - General Relativity (Minor)

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Prerequisites
none
### 5.125 Course: General Relativity II [T-PHYS-106678]

**Responsible:** Prof. Dr. Frans Klinkhamer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103333 - General Relativity II

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Legend: 🖥 Online, 🛠 Blended (On-Site/Online), 🔵 On-Site, ✗ Cancelled

**Prerequisites**

none
## 5.126 Course: General Relativity II (Minor) [T-PHYS-106679]

**Responsible:** Prof. Dr. Frans Klinkhamer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103334 - General Relativity II (Minor)

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Legend: 🖥 Online, 🪐 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.127 Course: Geological Hazards and Risk [T-PHYS-103525]

**Responsible:** Dr. Andreas Schäfer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-101833 - Geological Hazards and Risk

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**Legend:** 🖥 Online, 📥 Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled
5.128 Course: In-depth Module - Doing Culture - Self Assignment BAK [T-ZAK-112655]

**Responsible:** Dr. Christine Mielke  
Christine Myglas

**Organisation:**  
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**
At least two presentations must be given: An examination of another kind according to § 5 section 3 (3) in the form of a presentation in one of the chosen courses (3 ECT). In a third seminar, either (a) a presentation is held (preliminary study achievement) which remains not graded and a topic-related term paper is submitted or (b) a written exam is taken. The three courses can be selected individually from the 5 thematic blocks or – in exceptional cases and according to the agreement with the responsible lecturer – all three courses can be selected from one block in the sense of a specialization. In addition, an oral examination is taken, which relates to the content of two of the chosen three courses.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Annotation**
The content of the Basic Modul is helpful.
5.129 Course: In-depth Module - Global Cultures - Self Assignment BAK [T-ZAK-112658]

**Responsible:** Dr. Christine Mielke
Christine Myglas

**Organisation:**
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**
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In a third seminar, either (a) a presentation is held (preliminary study achievement) which remains not graded and a topic-related term paper is submitted or (b) a written exam is taken.
The three courses can be selected individually from the 5 thematic blocks or – in exceptional cases and according to the agreement with the responsible lecturer – all three courses can be selected from one block in the sense of a specialization.
In addition, an oral examination is taken, which relates to the content of two of the chosen three courses.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Annotation**
The content of the Basic Module is helpful.
5.130 Course: In-depth Module - Media & Aesthetics - Self Assignment BAK [T-ZAK-112656]

**Responsible:** Dr. Christine Mielke
Christine Myglas

**Organisation:**
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**
At least two presentations must be given: An examination of another kind according to § 5 section 3 (3) in the form of a presentation in one of the chosen courses (3 ECT).
In a third seminar, either (a) a presentation is held (preliminary study achievement) which remains not graded and a topic-related term paper is submitted or (b) a written exam is taken.
The three courses can be selected individually from the 5 thematic blocks or – in exceptional cases and according to the agreement with the responsible lecturer – all three courses can be selected from one block in the sense of a specialization.
In addition, an oral examination is taken, which relates to the content of two of the chosen three courses.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Annotation**
The content of the Basic Modul is helpful.
5.131 Course: In-depth Module - Spheres of Life - Self Assignment BAK [T-ZAK-112657]

**Responsible:** Dr. Christine Mielke
Christine Myglas

**Organisation:**
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**
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In a third seminar, either (a) a presentation is held (preliminary study achievement) which remains not graded and a topic-related term paper is submitted or (b) a written exam is taken.
The three courses can be selected individually from the 5 thematic blocks or – in exceptional cases and according to the agreement with the responsible lecturer – all three courses can be selected from one block in the sense of a specialization.
In addition, an oral examination is taken, which relates to the content of two of the chosen three courses.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary stduies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Annotation**
The content of the Basic Modul is helpful.
5.132 Course: In-depth Module - Technology & Responsibility - Self Assignment BAK [T-ZAK-112654]

**Responsible:**  Dr. Christine Mielke
Christine Myglas

**Organisation:**  M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**
At least two presentations must be given: An examination of another kind according to § 5 section 3 (3) in the form of a presentation in one of the chosen courses (3 ECT).
In a third seminar, either (a) a presentation is held (preliminary study achievement) which remains not graded and a topic-related term paper is submitted or (b) a written exam is taken.
The three courses can be selected individually from the 5 thematic blocks or – in exceptional cases and according to the agreement with the responsible lecturer – all three courses can be selected from one block in the sense of a specialization.
In addition, an oral examination is taken, which relates to the content of two of the chosen three courses.

**Prerequisites**
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.

**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Annotation**
The content of the Basic Module is helpful.
### 5.133 Course: In-Situ: Tectonics and Seismic Hazard in the Mediterranean Region [T-PHYS-112830]

**Responsible:** Prof. Dr. Andreas Rietbrock  
**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106322 - In-Situ: Tectonics and Seismic Hazard in the Mediterranean Region

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Legend: 🖥 Online, ☭ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Competence Certificate**  
Students solve exercise sheets, prepare and give a presentation and write a final report.
### 5.134 Course: Introduction to Cosmology [T-PHYS-102384]

**Responsible:** Prof. Dr. Guido Drexlin  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102175 - Introduction to Cosmology

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<td>2 SWS</td>
<td>Lecture / 📚</td>
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<td>Lecture / 📚</td>
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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### 5.135 Course: Introduction to Cosmology (Minor) [T-PHYS-102433]

**Responsible:** Prof. Dr. Guido Drexlin  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102176 - Introduction to Cosmology (Minor)

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**Events**

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| WT 21/22   | 4022022 | Übungen zur Einführung in die Kosmologie | 1 SWS | Practice / ONLINE | Drexlin, Huber |
| WT 22/23   | 4022021 | Einführung in die Kosmologie | 2 SWS | Lecture / ONLINE | Drexlin, Huber |
| WT 22/23   | 4022022 | Übungen zur Einführung in die Kosmologie | 1 SWS | Practice / ONLINE | Drexlin, Huber |
| WT 23/24   | 4022021 | Introduction to Cosmology | 2 SWS | Lecture / ONLINE | Drexlin, Lokhov |
| WT 23/24   | 4022022 | Exercises to Introduction to Cosmology | 1 SWS | Practice / ONLINE | Drexlin, Lokhov, Huber |

*Legend: 🖥 Online, 🗜 Blended (On-Site/Online), 🔔 On-Site, ✗ Cancelled*
### 5.136 Course: Introduction to Flavor Physics, Fundamentals [T-PHYS-105963]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102987 - Introduction to Flavor Physics, Fundamentals

<table>
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<td>Nierste, Ziegler, Shtabovenko</td>
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Legend: ⏩ Online, ₯ Blended (On-Site/Online), 🔔 On-Site, ✗ Cancelled
Course: Introduction to Flavor Physics, Fundamentals (Minor) [T-PHYS-106322]

**Responsibility:** Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103189 - Introduction to Flavor Physics, Fundamentals (Minor)

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| ST 2021 | 4026172 | Exercises to Introduction to Flavour Physics | 2 SWS | Practice / 🖥 | Nierste, Ziegler, Shtabovenko |

Legend: 🖥 Online, 📍 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### 5.138 Course: Introduction to Flavor Physics, Fundamentals and Advanced Topics [T-PHYS-105962]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102986 - Introduction to Flavor Physics, Fundamentals and Advanced Topics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗓 On-Site, ✗ Cancelled
### 5.139 Course: Introduction to Flavor Physics, Fundamentals and Advanced Topics (Minor) [T-PHYS-106321]

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Legend: 📖 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ⌚ Cancelled
# 5.140 Course: Introduction to General Relativity [T-PHYS-113186]

**Responsible:** Prof. Dr. Thomas Schwetz-Mangold  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106532 - Introduction to General Relativity

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Legend: 🝞 Online, 🏹 Blended (On-Site/Online), 🗒 On-Site, ✗ Cancelled
### 5.141 Course: Introduction to General Relativity (Minor) [T-PHYS-113189]

**Responsible:** Prof. Dr. Thomas Schwetz-Mangold  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106533 - Introduction to General Relativity (Minor)

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Legend: 🖤 Online, ☑ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.142 Course: Introduction to Neutron Scattering [T-PHYS-112831]

**Responsible:** PD Dr. Frank Weber  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106323 - Introduction to Neutron Scattering

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Legend: 🖥 Online, 🛡️ Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### 5.143 Course: Introduction to Neutron Scattering (Minor) [T-PHYS-112832]

**Responsible:** PD Dr. Frank Weber  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106324 - Introduction to Neutron Scattering (Minor)

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Legend: 🖥 Online, ☝ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.144 Course: Introduction to Scientific Methods [T-PHYS-102480]

Responsible: Studiendekan Physik

Organisation: KIT Department of Physics

Part of: M-PHYS-101397 - Introduction to Scientific Methods

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Prerequisites

none
## T.145 Course: Introduction to Theoretical Cosmology [T-PHYS-109887]

**Responsible:** TT-Prof. Dr. Felix Kahlhöfer  
Prof. Dr. Thomas Schwetz-Mangold  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104855 - Introduction to Theoretical Cosmology

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Legend: 🖥 Online, ☐ Blended (On-Site/Online), 🔴 On-Site, ☑ Cancelled

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Physics Master (Master of Science)  
Module Handbook as of 20/09/2023  
506
Course: Introduction to Theoretical Cosmology (Minor) [T-PHYS-109888]

Responsible: TT-Prof. Dr. Felix Kahlhöfer
                  Prof. Dr. Thomas Schwetz-Mangold

Organisation: KIT Department of Physics

Part of: M-PHYS-104856 - Introduction to Theoretical Cosmology (Minor)

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Legend: 🖥 Online,  ❁ Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### 5.147 Course: Introduction to Theoretical Particle Physics, with ext. Exercises [T-PHYS-104536]

**Responsible:**
- PD Dr. Stefan Gieseke
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner
- Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102221 - Introduction to Theoretical Particle Physics, with ext. Exercises

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**Prerequisites**

none

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
Course: Introduction to Theoretical Particle Physics, with ext. Exercises (Minor) [T-PHYS-104791]

---

**Responsible:** PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102424 - Introduction to Theoretical Particle Physics, with ext. Exercises (Minor)

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**Type** | **Completed coursework** | **Credits** | **Grading scale** | **Version**
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**Prerequisites**

none
# 5.149 Course: Introduction to Theoretical Particle Physics, without ext. Exercises [T-PHYS-104792]

**Responsible:**
- PD Dr. Stefan Gieseke
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner
- Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102425 - Introduction to Theoretical Particle Physics, without ext. Exercises

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Legend: Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5.150 Course: Introduction to Theoretical Particle Physics, without ext. Exercises (Minor) [T-PHYS-104793]

**Responsible:** PD Dr. Stefan Gieseke  
Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102426 - Introduction to Theoretical Particle Physics, without ext. Exercises (Minor)

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Legend: 🖥 Online, 🗣️ Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
# 5.151 Course: Inversion and Tomography [T-PHYS-104737]

**Responsible:** Prof. Dr. Thomas Bohlen
apl. Prof. Dr. Joachim Ritter

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102368 - Inversion and Tomography

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled
### 5.152 Course: Inversion and Tomography (Minor) [T-PHYS-105572]

**Responsible:** Prof. Dr. Thomas Bohlen  
apl. Prof. Dr. Joachim Ritter

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102658 - Inversion and Tomography (Minor)

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| ST 21 | 4060232 | Exercises to Inversion and Tomography | 2 SWS | Practice / 🖥 | Ritter, Bie |
| ST 22 | 4060231 | Inversion and Tomography | 2 SWS | Lecture / 🖥 | Ritter |
| ST 22 | 4060232 | Exercises to Inversion and Tomography | 2 SWS | Practice / 🖥 | Ritter, NN |
| ST 23 | 4060231 | Inversion and Tomography | 2 SWS | Lecture / 🖥 | Ritter |
| ST 23 | 4060232 | Exercises to Inversion and Tomography | 2 SWS | Practice / 🖥 | Ritter, Gao |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, x Cancelled
5.153 Course: Master's Thesis [T-PHYS-113096]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106481 - Master's Thesis

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**Prerequisites**
none

**Final Thesis**
This course represents a final thesis. The following periods have been supplied:

- **Submission deadline** 6 months
- **Maximum extension period** 3 months
- **Correction period** 8 weeks

This thesis requires confirmation by the examination office.
5.154 Course: Mathematical Methods of Theoretical Physics (two hours per week) [T-PHYS-111704]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105834 - Mathematical Methods of Theoretical Physics (two hours per week)

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Legend: 🖥 Online, 📦 Blended (On-Site/Online), 🗣️ On-Site, ☑️ Cancelled
### 5.155 Course: Mathematical Methods of Theoretical Physics (two hours per week) (Minor) [T-PHYS-111705]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105835 - Mathematical Methods of Theoretical Physics (two hours per week) (Minor)

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Legend: 🖥 Online, 🤖 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.156 Course: Measurement Methods and Techniques in Experimental Physics, with ext. Exercises [T-PHYS-102376]

**Responsible:** Prof. Dr. Guido Drexlin
PD Dr. Frank Hartmann
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102517 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises

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Legend: 🗣 Online, 📦 Blended (On-Site/Online), 👤 On-Site, ✗ Cancelled
### 5.157 Course: Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor) [T-PHYS-105106]

**Responsible:** Prof. Dr. Guido Drexlin  
PD Dr. Frank Hartmann  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102519 - Measurement Methods and Techniques in Experimental Physics, with ext. Exercises (Minor)

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**5.158 Course: Measurement Methods and Techniques in Experimental Physics, without ext. Exercises [T-PHYS-105105]**

**Responsible:** Prof. Dr. Guido Drexlin  
PD Dr. Frank Hartmann  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102518 - Measurement Methods and Techniques in Experimental Physics, without ext. Exercises

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Legend: 🖥 Online, 🔄 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.159 Course: Measurement Methods and Techniques in Experimental Physics, without ext. Exercises (Minor) [T-PHYS-106327]

**Responsible:** Prof. Dr. Guido Drexlin  
PD Dr. Frank Hartmann  
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103194 - Measurement Methods and Techniques in Experimental Physics, without ext. Exercises (Minor)

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.160 Course: Methods of Data Analysis [T-PHYS-111426]

**Responsible:** Prof. Dr. Joaquim José Ginete Werner Pinto  
Prof. Dr. Peter Knippertz

**Organisation:** KIT Department of Physics

**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Competence Certificate**  
Successful participation in the exercises.

**Prerequisites**  
None

**Recommendation**  
None

**Annotation**  
None
5.161 Course: Microscale Fluid Mechanics [T-MACH-113144]

**Responsible:** Dr.-Ing. Philipp Marthaler  
**Organisation:** KIT Department of Mechanical Engineering  
**Part of:** M-MACH-106539 - Microscale Fluid Mechanics

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| WT 23/24 | 2153451 | Microscale Fluid Mechanics | 2 SWS | Lecture / Marthaler |

Legend: 🖥 Online, ⚫ Blended (On-Site/Online), 💬 On-Site, ❌ Cancelled

**Competence Certificate**

Oral exam, duration: approximately 30 minutes  
no tools or reference materials may be used during the exam

**Prerequisites**

none
5.162 Course: Middle Atmosphere in the Climate System [T-PHYS-111413]

**Responsible:** PD Dr. Michael Höpfner  
Dr. Miriam Sinnhuber  

**Organisation:** KIT Department of Physics  

**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, ☝️ Blended (On-Site/Online), 🛑 On-Site, ✗Cancelled

**Competence Certificate**  
Short presentation at the end of the semester

**Prerequisites**  
None

**Recommendation**  
None

**Annotation**  
None
### 5.163 Course: Modern Methods of Data Analysis, with ext. Exercises [T-PHYS-102495]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Roger Wolf  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102127 - Modern Methods of Data Analysis, with ext. Exercises

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**Legend:** 🖥️ Online, 🧩 Blended (On-Site/Online), 🈸 On-Site, ✗ Cancelled

**Prerequisites**

none
# 5.164 Course: Modern Methods of Data Analysis, with ext. Exercises (Minor) [T-PHYS-102496]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Roger Wolf  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102128 - Modern Methods of Data Analysis, with ext. Exercises (Minor)

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*Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, x Cancelled*

**Prerequisites**

none
Course: Modern Methods of Data Analysis, without ext. Exercises [T-PHYS-102494]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102125 - Modern Methods of Data Analysis, without ext. Exercises

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**Events**

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| ST 2021 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / Online | Chwalek, Wolf |
| ST 2022 | 4022141 | Advanced statistical methods and machine learning | 2 SWS | Lecture / On-Site | Goldenzweig, Wolf |
| ST 2022 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / Blended | Metzner, Goldenzweig, Wolf |
| ST 2023 | 4022141 | Advanced statistical methods and machine learning | 2 SWS | Lecture / On-Site | Goldenzweig, Wolf |
| ST 2023 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / On-Site | Stefkova, Goldenzweig, Wolf |

**Legend:**  
Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**  
none
**Course: Modern Methods of Data Analysis, without ext. Exercises (Minor) [T-PHYS-102497]**

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102126 - Modern Methods of Data Analysis, without ext. Exercises (Minor)

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| ST 2021 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / 📚 | Chwalek, Wolf |
| ST 2022 | 4022141 | Advanced statistical methods and machine learning | 2 SWS | Lecture / 📚 | Goldenzweig, Wolf |
| ST 2022 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / 📚 | Metzner, Goldenzweig, Wolf |
| ST 2023 | 4022141 | Advanced statistical methods and machine learning | 2 SWS | Lecture / 📚 | Goldenzweig, Wolf |
| ST 2023 | 4022142 | Moderne Methoden der Datenanalyse: Computerpraktikum | 2 SWS | Practical course / 📚 | Stefkova, Goldenzweig, Wolf |

**Legend:** 📚 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
### 5.167 Course: Modern Methods of Spectroscopy: Applications in Astroparticle Physics [T-PHYS-112237]

| Responsible          | Prof. Dr. Guido Drexlin  
|                      | Prof. Dr. Kathrin Valerius |
| Organisation         | KIT Department of Physics |
| Part of              | M-PHYS-106047 - Modern Methods of Spectroscopy: Applications in Astroparticle Physics |

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Legend: 🖥 Online, ❌ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
**5.168 Course: Molecular Electronics [T-PHYS-109305]**

**Responsible:** Prof. Dr. Wulf Wulfhekel  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104540 - Molecular Electronics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled

**Prerequisites**

none
5.169 Course: Molecular Electronics (Minor) [T-PHYS-109306]

**Responsible:** Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104541 - Molecular Electronics (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗺 On-Site, ✗ Cancelled

**Prerequisites**

none
5.170 Course: Molecular Spectroscopy [T-CHEMBIO-104639]

Responsible: apl. Prof. Dr. Andreas-Neil Unterreiner
Organisation: KIT Department of Chemistry and Biosciences
KIT Department of Physics
Part of: M-PHYS-102337 - Molecular Spectroscopy

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled
5.171 Course: Monte Carlo Event Generators [T-PHYS-109892]

**Responsible:** PD Dr. Stefan Gieseke

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104860 - Monte Carlo Event Generators

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**Prerequisites**

none
### 5.172 Course: Monte Carlo Event Generators (Minor) [T-PHYS-109893]

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**Responsible:** PD Dr. Stefan Gieseke  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104861 - Monte Carlo Event Generators (Minor)

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### 5.173 Course: Nanomaterials, with Exercises [T-PHYS-110285]

**Responsible:** Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105068 - Nanomaterials, with Exercises

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## 5.174 Course: Nanomaterials, with Exercises (Minor) [T-PHYS-110286]

**Responsible:** Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105069 - Nanomaterials, with Exercises (Minor)

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5.175 Course: Nanomaterials, without Exercises [T-PHYS-110288]

**Responsible:** Dr. Thomas Reisinger  
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105071 - Nanomaterials, without Exercises

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### Course: Nano-Optics [T-PHYS-102282]

**Responsible:** PD Dr. Andreas Naber  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102146 - Nano-Optics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### Course: Nano-Optics (Minor) [T-PHYS-102360]

**Responsible:** PD Dr. Andreas Naber  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102147 - Nano-Optics (Minor)

#### Type
- Completed coursework

#### Credits
- 8

#### Grading scale
- pass/fail

#### Version
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5.178 Course: New Light Particles Beyond the Standard Model [T-PHYS-111115]

**Responsible:** Prof. Dr. Ulrich Nierste  
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105534 - New Light Particles Beyond the Standard Model

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5.179 Course: New Light Particles Beyond the Standard Model (Minor) [T-PHYS-111196]

**Responsible:** Prof. Dr. Ulrich Nierste
Dr. Robert Ziegler

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105582 - New Light Particles Beyond the Standard Model (Minor)

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### 5.180 Course: New Light Particles Beyond the Standard Model, without Exercises [T-PHYS-111703]

**Responsible:** Prof. Dr. Ulrich Nierste  
Dr. Robert Ziegler  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-105833 - New Light Particles Beyond the Standard Model, without Exercises  

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Legend: 🖥 Online, ⚡ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.181 Course: Nonlinear Optics [T-ETIT-101906]

**Responsible:** Prof. Dr.-Ing. Christian Koos  
**Organisation:** KIT Department of Electrical Engineering and Information Technology  
**Part of:** M-ETIT-100430 - Nonlinear Optics

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**Prerequisites**

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
# 5.183 Course: Ocean-Atmosphere Interactions [T-PHYS-111414]

**Responsible:** Prof. Dr. Andreas Fink  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Competence Certificate**  
Active participation

**Prerequisites**  
None

**Recommendation**  
None

**Annotation**  
None
**Course: Oral Exam - Supplementary Studies on Culture and Society [T-ZAK-112659]**

**Responsible:** Dr. Christine Mielke  
Christine Myglas  

**Organisation:**  
Part of: M-ZAK-106235 - Supplementary Studies on Culture and Society

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**Competence Certificate**  
An oral examination according to § 7 section 6 of approx. 45 minutes on the contents of two courses from In-depth Module.

**Prerequisites**  
Prerequisite for the 'Oral Examination' is the successful completion of Modules 1 and 3 and the required elective sections in Module 2.
5.185 Course: Oral Exam - Supplementary Studies on Sustainable Development [T-ZAK-112351]

**Organisation:**
Part of: M-ZAK-106099 - Supplementary Studies on Sustainable Development

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**Competence Certificate**
An oral examination according to § 7 section 6 of approx. 45 minutes on the contents of two courses from Elective Module.

**Prerequisites**
A requirement for the Supplementary Course: Oral examination is the successful completion of the modules Basics Module and Specialisation Module and the required electives of Elective Module.
5.186 Course: Particle Physics I [T-PHYS-102369]

**Responsible:**
- Prof. Dr. Torben Ferber
- Prof. Dr. Ulrich Husemann
- Prof. Dr. Markus Klute
- Prof. Dr. Günter Quast
- PD Dr. Klaus Rabbertz

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102114 - Particle Physics I

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Legend: 📱 Online, 🚀 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**
none
## Course: Particle Physics I (Minor) [T-PHYS-102488]

### Responsible:
- Prof. Dr. Torben Ferber
- Prof. Dr. Ulrich Husemann
- Prof. Dr. Markus Klute
- Prof. Dr. Günter Quast
- PD Dr. Klaus Rabbertz

### Organisation:
- KIT Department of Physics

### Part of:
- M-PHYS-102115 - Particle Physics I (Minor)

### Type
- Completed coursework

### Credits
- 8

### Grading scale
- pass/fail

### Recurrence
- Each winter term

### Version
- 1

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 👤 On-Site, ❌ Cancelled

### Prerequisites
- none
5.188 Course: Particle Physics II - Flavour Physics, with ext. Exercises [T-PHYS-104783]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102422 - Particle Physics II - Flavour Physics, with ext. Exercises

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*Legend:* 🖥 Online, 🕐 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**
none
### 5.189 Course: Particle Physics II - Flavour Physics, with ext. Exercises (Minor) [T-PHYS-106316]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103183 - Particle Physics II - Flavour Physics, with ext. Exercises (Minor)

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**Legend:** 🖥 Online, 🚀 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
Course: Particle Physics II - Flavour Physics, without ext. Exercises [T-PHYS-102371]

Responsible: Prof. Dr. Torben Ferber
Dr. Pablo Goldenzweig
Prof. Dr. Ulrich Nierste

Organisation: KIT Department of Physics

Part of: M-PHYS-102154 - Particle Physics II - Flavour Physics, without ext. Exercises

Type: Oral examination
Credits: 6
Grading scale: Grade to a third
Recurrence: Each winter term
Version: 1

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

Prerequisites
none
5.191 Course: Particle Physics II - Flavour Physics, without ext. Exercises (Minor) [T-PHYS-102424]

**Responsible:** Prof. Dr. Torben Ferber  
Dr. Pablo Goldenzweig  
Prof. Dr. Ulrich Nierste

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102155 - Particle Physics II - Flavour Physics, without ext. Exercises (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
5.192 Course: Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises [T-PHYS-111950]

**Responsible:** Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105939 - Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises

### Events

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**Prerequisites**

none
Course: Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises (Minor) [T-PHYS-111951]

**Responsible:** Prof. Dr. Markus Klute

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105940 - Particle Physics II - Physics Beyond the Standard Model, with ext. Exercises (Minor)

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**Prerequisites**

none
### 5.194 Course: Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises [T-PHYS-111948]

**Responsible:** Prof. Dr. Markus Klute  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105937 - Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises

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Legend: 🖥 Online, ☰ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**  
none
5.195 Course: Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises (Minor) [T-PHYS-111949]

**Responsible:** Prof. Dr. Markus Klute  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105938 - Particle Physics II - Physics Beyond the Standard Model, without ext. Exercises (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
5.196 Course: Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises [T-PHYS-108474]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104088 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises

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**Events**

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**

none
5.197 Course: Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor) [T-PHYS-108475]

**Responsible:** Prof. Dr. Thomas Müller
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104089 - Particle Physics II - Top Quarks and Jets at the LHC, with ext. Exercises (Minor)

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**Prerequisites**
none
### 5.198 Course: Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises [T-PHYS-108472]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104086 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises

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**Legend:** 🖥 Online, 🚀 Blended (On-Site/Online), 🗣 On-Site, 🗑 Cancelled

**Prerequisites**

none
5.199 Course: Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor) [T-PHYS-108473]

**Responsible:** Prof. Dr. Thomas Müller  
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104087 - Particle Physics II - Top Quarks and Jets at the LHC, without ext. Exercises (Minor)

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Legend: 🖥 Online, ☭ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
Course: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises [T-PHYS-108470]

5.200 Course: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises [T-PHYS-108470]

**Responsible:**
- Prof. Dr. Günter Quast
- PD Dr. Klaus Rabbertz
- PD Dr. Roger Wolf

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-104084 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises

**Type:** Oral examination

**Credits:** 8

**Grading scale:** Grade to a third

**Recurrence:** Each summer term

**Version:** 1

### Events

| ST 2021 | 4022161 | Teilchenphysik II - W, Z und Higgs an Collidern | 2 SWS | Lecture / 🖥 | Wolf |
| ST 2021 | 4022162 | Übungen zu Teilchenphysik II - W, Z und Higgs an Collidern | 1 SWS | Practice / 🤓 | Wolf, NN |
| ST 2023 | 4022161 | Teilchenphysik II - W, Z, Higgs am Collider | 2 SWS | Lecture / 🤓 | Rabbertz, Faltermann |
| ST 2023 | 4022162 | Übungen zu Teilchenphysik II - W, Z, Higgs am Collider | 1 SWS | Practice / 🤓 | Rabbertz, Faltermann, Zuo |

**Legend:**
- 🖥 Online
- 🧩 Blended (On-Site/Online)
- 🤓 On-Site
- ✗ Cancelled

**Prerequisites**
none
### 5.201 Course: Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor) [T-PHYS-108471]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz  
PD Dr. Roger Wolf  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-104085 - Particle Physics II - W, Z, Higgs at Colliders, with ext. Exercises (Minor)

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**Events**

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| ST 2021 | 4022162 | Übungen zu Teilchenphysik II - W, Z und Higgs an Collidern | 1 SWS | Practice/🖥 | Wolf, NN |
| ST 2023 | 4022161 | Teilchenphysik II - W, Z, Higgs am Collider | 2 SWS | Lecture/🗣 | Rabbertz, Faltermann |
| ST 2023 | 4022162 | Übungen zu Teilchenphysik II - W, Z, Higgs am Collider | 1 SWS | Practice/🗣 | Rabbertz, Faltermann, Zuo |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.202 Course: Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises [T-PHYS-108468]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104081 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises

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**Events**

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| ST 2021 | 4022162 | Übungen zu Teilchenphysik II - W, Z und Higgs an Collidern | 1 SWS | Practice / 🖥 | Wolf, NN |
| ST 2023 | 4022161 | Teilchenphysik II - W, Z, Higgs am Collider | 2 SWS | Lecture / 🗣 | Rabbertz, Faltermann |
| ST 2023 | 4022162 | Übungen zu Teilchenphysik II - W, Z, Higgs am Collider | 1 SWS | Practice / 🗣 | Rabbertz, Faltermann, Zuo |

*Legend: 🖥 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled*

**Prerequisites**

none
5.203 Course: Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor) [T-PHYS-108469]

**Responsible:** Prof. Dr. Günter Quast  
PD Dr. Klaus Rabbertz  
PD Dr. Roger Wolf

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104082 - Particle Physics II - W, Z, Higgs at Colliders, without ext. Exercises (Minor)

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**Events**

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| ST 2021 | 4022162 | Übungen zu Teilchenphysik II - W, Z und Higgs an Collidern | 1 SWS | Practice / 🖥 | Wolf, NN |
| ST 2023 | 4022161 | Teilchenphysik II - W, Z, Higgs am Collider | 2 SWS | Lecture / 🗣 | Rabbertz, Faltermann |
| ST 2023 | 4022162 | Übungen zu Teilchenphysik II - W, Z, Higgs am Collider | 1 SWS | Practice / 🗣 | Rabbertz, Faltermann, Zuo |

Legend: 🖥 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, × Cancelled

**Prerequisites**
none
### 5.204 Course: Particle Physics with Extra Dimensions [T-PHYS-112244]

**Responsible:** Dr. Monika Blanke  
Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106055 - Particle Physics with Extra Dimensions  

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Legend: 🖥 Online, ☓ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.205 Course: Photovoltaics [T-ETIT-101939]

**Responsible:** Prof. Dr.-Ing. Michael Powalla

**Organisation:** KIT Department of Electrical Engineering and Information Technology

**Part of:** M-ETIT-100513 - Photovoltaics

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*Legend:* 🖥️ Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

"M-ETIT-100524 - Solar Energy" must not have started.
5.206 Course: Physics of Planetary Atmospheres [T-PHYS-109177]

Responsible: Prof. Dr. Thomas Leisner
Organisation: KIT Department of Physics
Part of: M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)
M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), On-Site, ✗ Cancelled

Competence Certificate
- If this module is part of the Specialization or Compulsory Subject, credits are earned through the associated exam (oral, written or otherwise).
- Otherwise, the exercises, computer exercises, internships or, if necessary, graduation lectures must be successfully completed.

Prerequisites
None

Recommendation
Basic knowledge of physics, physical chemistry and fluid dynamics at Bachelor level.

Annotation
180 hours consisting of attendance times (42 hours), follow-up of the lecture and editing exercises (138 hours).
### 5.207 Course: Physics of Seismic Instruments [T-PHYS-104727]

**Responsible:** Dr. Thomas Forbriger  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102358 - Physics of Seismic Instruments

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*Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🔵 On-Site, ✗ Cancelled*
### 5.208 Course: Physics of Seismic Instruments (Minor) [T-PHYS-105567]

**Responsible:** Dr. Thomas Forbriger  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102653 - Physics of Seismic Instruments (Minor)

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**Legend:**  
🖥 Online, 🛠 Blended (On-Site/Online), 🗽 On-Site, ✗ Cancelled
### 5.209 Course: Physics of Semiconductors, with Exercises [T-PHYS-102343]

**Responsible:** Prof. Dr. Heinz Kalt  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102131 - Physics of Semiconductors, with Exercises

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### 5.210 Course: Physics of Semiconductors, with Exercises (Minor) [T-PHYS-102301]

**Responsible:** Prof. Dr. Heinz Kalt  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102130 - Physics of Semiconductors, with Exercises (Minor)

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| ST 2021  | 4020112 | Übungen zu Halbleiterphysik | 1 SWS | Practice / 🖥 | Kalt, N. |
| ST 2022  | 4020111 | Halbleiterphysik | 4 SWS | Lecture / 🛒 | Kalt |
| ST 2022  | 4020112 | Übungen zu Halbleiterphysik | 1 SWS | Practice / 🛒 | Kalt, Kalt |

Legend: 🖥 Online, Blended (On-Site/Online), 🛒 On-Site, ✗ Cancelled
### 5.211 Course: Physics of Semiconductors, without Exercises [T-PHYS-104590]

**Responsible:** Prof. Dr. Heinz Kalt  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102301 - Physics of Semiconductors, without Exercises

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## 5.212 Course: Practice Module [T-ZAK-112660]

**Responsible:** Dr. Christine Mielke  
Christine Myglas

**Organisation:**  
Part of: [M-ZAK-106235 - Supplementary Studies on Culture and Society](#)

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**Competence Certificate**
Internship (3 ECT)  
Report within the framework of the practical training (Length approx. 18,000 characters (incl. spaces) (1 ECT)

**Prerequisites**
none

**Annotation**
Knowledge from the Basic Module and the Elective Module is helpful.
### 5.213 Course: Precision Phenomenology at Colliders and Computational Methods, with Exercises [T-PHYS-111279]

**Responsible:** Prof. Dr. Gudrun Heinrich  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105640 - Precision Phenomenology at Colliders and Computational Methods, with Exercises

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T 5.214 Course: Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor) [T-PHYS-111281]

**Responsible:** Prof. Dr. Gudrun Heinrich  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105642 - Precision Phenomenology at Colliders and Computational Methods, with Exercises (Minor)

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### 5.215 Course: Precision Phenomenology at Colliders and Computational Methods, without Exercises [T-PHYS-111280]

| Responsible: | Prof. Dr. Gudrun Heinrich |
| Organisation: | KIT Department of Physics |
| Part of: | M-PHYS-105641 - Precision Phenomenology at Colliders and Computational Methods, without Exercises |

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5.216 Course: Quantum Detectors and Sensors [T-PHYS-112582]

**Responsible:** Prof. Dr. Sebastian Kempf

**Organisation:**
- KIT Department of Electrical Engineering and Information Technology
- KIT Department of Physics

**Part of:** M-PHYS-106193 - Quantum Detectors and Sensors

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**Legend:** 🖥 Online, 🕹️ Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### 5.217 Course: Quantum Detectors and Sensors (Minor) [T-PHYS-112583]

**Responsible:** Prof. Dr. Sebastian Kempf  
**Organisation:** KIT Department of Electrical Engineering and Information Technology  
KIT Department of Physics  
**Part of:** M-PHYS-106194 - Quantum Detectors and Sensors (Minor)

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Legend: 🍭 Online, 🍭 Blended (On-Site/Online), 🍭 On-Site, ✗ Cancelled
# 5.218 Course: Quantum Optics at the Nano Scale, with Exercises [T-PHYS-113126]

**Responsible:** Prof. Dr. David Hunger  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106508 - Quantum Optics at the Nano Scale, with Exercises  

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*Legend: 🖥 Online, 🕰 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled*

### Prerequisites

none
**Course: Quantum Optics at the Nano Scale, with Exercises (Minor) [T-PHYS-113127]**

**Responsible:** Prof. Dr. David Hunger  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106509 - Quantum Optics at the Nano Scale, with Exercises (Minor)

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Legend: 🖥 Online, 🤨 Blended (On-Site/Online), 🗣️ On-Site, ☑️ Cancelled

**Prerequisites**

none
**5.220 Course: Quantum Optics at the Nano Scale, without Exercises [T-PHYS-113128]**

**Responsible:** Prof. Dr. David Hunger  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106510 - Quantum Optics at the Nano Scale, without Exercises

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Legend: 🖥 Online, 📦 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**

none
5.221 Course: Remote Sensing of Atmosphere and Ocean [T-PHYS-111424]

**Responsible:** Prof. Dr. Björn-Martin Sinnhuber

**Organisation:** KIT Department of Physics

**Part of:**
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Competence Certificate**

More than 50% of the points from the exercises must be achieved.

**Prerequisites**

None

**Recommendation**

None

**Annotation**

None
Course: Seismic Data Processing, Coursework [T-PHYS-108686]

**Responsible:** Prof. Dr. Thomas Bohlen  
Dr. Thomas Hertweck

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-104186 - Seismic Data Processing with Final Report (Graded)

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Physics Master (Master of Science)  
Module Handbook as of 20/09/2023
# 5.223 Course: Seismic Data Processing, Final Report (Graded) [T-PHYS-108656]

**Responsible:** Prof. Dr. Thomas Bohlen  
Dr. Thomas Hertweck  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-104186 - Seismic Data Processing with Final Report (Graded)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**  
Successful participation on "Seismic Data Processing, course achievement"

**Modeled Conditions**  
The following conditions have to be fulfilled:

1. The course **T-PHYS-108686 - Seismic Data Processing, Coursework** must have been passed.
5.224 Course: Seismic Modeling [T-PHYS-110605]

Responsible: Prof. Dr. Thomas Bohlen
Organisation: KIT Department of Physics
Part of: M-PHYS-105227 - Seismic Modeling

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### 5.225 Course: Seismic Modeling (Minor) [T-PHYS-110607]

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**Responsible:** Prof. Dr. Thomas Bohlen  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105228 - Seismic Modeling (Minor)

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5.226 Course: Seismics [T-PHYS-112843]

**Responsible:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106326 - Seismics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.227 Course: Seismics (Minor) [T-PHYS-112833]

**Responsible:** Prof. Dr. Thomas Bohlen  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106325 - Seismics (Minor)

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5.228 Course: Seismology [T-PHYS-110603]

**Responsible:** Prof. Dr. Andreas Rietbrock  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105225 - Seismology

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**Prerequisites**

none
### 5.229 Course: Seismology (Minor) [T-PHYS-110604]

**Responsible:** Prof. Dr. Andreas Rietbrock  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105226 - Seismology (Minor)

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#### Prerequisites

none
5.230 Course: Selfassignment-MScPhysics-graded [T-PHYS-111562]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-101394 - Interdisciplinary Qualifications

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**Self service assignment of supplementary studies**

This course can be used for self service assignment of grade acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
5.231 Course: Selfassignment-MScPhysics-ungraded [T-PHYS-111565]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-101394 - Interdisciplinary Qualifications

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**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
## 5.232 Course: Seminar on IPCC Assessment Report [T-PHYS-111410]

**Responsible:** Prof. Dr. Joaquim José Ginete Werner Pinto  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Legend:** 🖥 Online, 🛠️ Blended (On-Site/Online), 🗣 On-Site, ⏹️ Cancelled

**Competence Certificate**  
Study of a chapter of the current IPCC report with subsequent presentation (~ 20-25 min) and submission of a written summary (1 page).

**Prerequisites**  
none

**Recommendation**  
none

**Annotation**  
none
Course: Solid State Quantum Computing [T-PHYS-111118]

Responsible: Prof. Dr. Alexey Ustinov
Organisation: KIT Department of Physics
Part of: M-PHYS-105537 - Solid State Quantum Computing

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| WT 21/22 | 4021081 | Solid-State Quantum Computing | 2 SWS | Lecture / Online | Ustinov |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗼 On-Site, ✗ Cancelled
### 5.234 Course: Solid State Quantum Computing, with Exercises [T-PHYS-111804]

**Responsible:** Prof. Dr. Alexey Ustinov  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105871 - Solid State Quantum Computing, with Exercises

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
5.235 Course: Solid State Quantum Computing, with Exercises (Minor) [T-PHYS-111805]

**Responsible:** Prof. Dr. Alexey Ustinov

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105872 - Solid State Quantum Computing, with Exercises (Minor)

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
# 5.236 Course: Solid State Quantum Technologies [T-PHYS-109890]

**Responsible:** Prof. Dr. Wolfgang Wernsdorfer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104858 - Solid State Quantum Technologies (Minor)

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*Legend:* 🖥 Online, ☺️ Blended (On-Site/Online), ☻ On-Site, ☒ Cancelled
## 5.237 Course: Solid State Quantum Technologies [T-PHYS-109889]

**Responsible:** Prof. Dr. Wolfgang Wernsdorfer  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104857 - Solid State Quantum Technologies

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### 5.238 Course: Solid-State Optics, without Exercises [T-PHYS-104773]

**Responsible:**  
PD Dr. Michael Hetterich  
Prof. Dr. Heinz Kalt

**Organisation:**  
KIT Department of Physics

**Part of:**  
M-PHYS-102408 - Solid-State Optics

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 👤 On-Site, ✗ Cancelled

**Prerequisites**  
none
5.239 Course: Solid-State Optics, without Exercises (Minor) [T-PHYS-104774]

**Responsible:** PD Dr. Michael Hetterich
Prof. Dr. Heinz Kalt

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102409 - Solid-State Optics (Minor)

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**Prerequisites**

- none

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### 5.240 Course: Specialisation Module - Self Assignment BeNe [T-ZAK-112346]

**Responsible:** Christine Myglas  
**Organisation:**  
**Part of:** M-ZAK-106099 - Supplementary Studies on Sustainable Development

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**Competence Certificate**
The monitoring occurs in the form of several supplementary courses, which usually comprise a presentation of the (group) project, a written elaboration of the (group) project as well as an individual term paper, if necessary with appendices (examination performances of other kind according to statutes § 5 section 3 No. 3 or § 7 section 7).
The presentation is usually with the accompanying practice partners, as well as the written paper.

**Prerequisites**
Active participation in all three mandatory components.

**Self service assignment of supplementary studies**
This course can be used for self service assignment of grade acquired from the following study providers:

- Zentrum für Angewandte Kulturwissenschaft und Studium Generale
- ZAK Begleitstudium

**Recommendation**
Knowledge from 'Basic Module' and 'Elective Module' is helpful.
5.241 Course: Specialization Phase [T-PHYS-102481]

**Responsible:** Studiendekan Physik

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-101396 - Specialization Phase

### Prerequisites

none

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5.242 Course: Spin Transport in Nanostructures [T-PHYS-104586]

**Responsible:** apl. Prof. Dr. Detlef Beckmann  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102293 - Spin Transport in Nanostructures

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**Legend:** 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ⏿ Cancelled

**Prerequisites**
none
## 5.243 Course: Spin Transport in Nanostructures (Minor) [T-PHYS-110858]

**Responsible:** apl. Prof. Dr. Detlef Beckmann  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105375 - Spin Transport in Nanostructures (Minor)

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**Legend:**  
- 🖥 Online  
- 🎤 Blended (On-Site/Online)  
- 🗣 On-Site  
- ✖ Cancelled

### Prerequisites

none
# 5.244 Course: Superconducting Nanostructures [T-PHYS-104513]

**Responsible:** apl. Prof. Dr. Detlef Beckmann  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102191 - Superconducting Nanostructures

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Legend: 🖥 Online, ☑ Blended (On-Site/Online), ‼ On-Site, ☒ Cancelled

**Prerequisites**  
none
**Course: Superconducting Nanostructures (Minor) [T-PHYS-109621]**

**Responsible:** apl. Prof. Dr. Detlef Beckmann  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-104723 - Superconducting Nanostructures (Minor)

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**Prerequisites**

none
### 5.246 Course: Superconductivity, Josephson Effect and Applications, with Exercises [T-PHYS-111293]

**Responsible:** Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105655 - Superconductivity, Josephson Effect and Applications, with Exercises

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### 5.247 Course: Superconductivity, Josephson Effect and Applications, with Exercises (Minor) [T-PHYS-111294]

**Responsible:** Prof. Dr. Alexander Shnirman  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105656 - Superconductivity, Josephson Effect and Applications, with Exercises (Minor)

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5.248 Course: Superconductivity, Josephson Effect and Applications, without Exercises [T-PHY-113257]

**Responsible:** Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHY-106584 - Superconductivity, Josephson Effect and Applications, without Exercises

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5.249 Course: Surface Science, with Exercises [T-PHYS-113098]

**Responsible:** TT-Prof. Dr. Philip Willke  
Prof. Dr. Wulf Wulfhekel  
PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106482 - Surface Science, with Exercises

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**Prerequisites**

none
### 5.250 Course: Surface Science, with Exercises (Minor) [T-PHYS-113100]

**Responsible:**
- TT-Prof. Dr. Philip Willke
- Prof. Dr. Wulf Wulfhekel
- PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106484 - Surface Science, with Exercises (Minor)

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**Prerequisites**
none
5.251 Course: Surface Science, without Exercises [T-PHYS-113099]

**Responsible:** TT-Prof. Dr. Philip Willke  
Prof. Dr. Wulf Wulfhekel  
PD Dr. Khalil Zakeri-Lori

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106483 - Surface Science, without Exercises

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**
none
# 5.252 Course: Symmetries and Groups [T-PHYS-104596]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102317 - Symmetries and Groups

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**Prerequisites**
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5.253 Course: Symmetries and Groups (Minor) [T-PHYS-104597]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102318 - Symmetries and Groups (Minor)

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**Prerequisites**

none
# 5.254 Course: Symmetries, Groups and Extended Gauge Theories [T-PHYS-102393]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102315 - Symmetries, Groups and Extended Gauge Theories

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**Prerequisites**
none
## 5.255 Course: Symmetries, Groups and Extended Gauge Theories (Minor) [T-PHYS-102444]

**Responsible:** Prof. Dr. Ulrich Nierste  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102316 - Symmetries, Groups and Extended Gauge Theories (Minor)

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### Prerequisites

none
5.256 Course: The ABC of DFT [T-PHYS-105960]

**Responsible:** Prof. Dr. Carsten Rockstuhl
Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102984 - The ABC of DFT

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
## 5.257 Course: Theoretical Molecular Biophysics, with Seminar [T-PHYS-102365]

### Responsible:
Prof. Dr. Wolfgang Wenzel

### Organisation:
KIT Department of Physics

### Part of:
M-PHYS-102169 - Theoretical Molecular Biophysics, with Seminar

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### 5.259 Course: Theoretical Molecular Biophysics, without Seminar [T-PHYS-104473]

**Responsible:** Prof. Dr. Wolfgang Wenzel  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102171 - Theoretical Molecular Biophysics, without Seminar

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Physics Master (Master of Science)  
Module Handbook as of 20/09/2023
**Course: Theoretical Molecular Biophysics, without Seminar (Minor) [T-PHYS-104474]**

**Responsible:** Prof. Dr. Wolfgang Wenzel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102172 - Theoretical Molecular Biophysics, without Seminar (Minor)

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**5.261 Course: Theoretical Nanooptics [T-PHYS-104587]**

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102295 - Theoretical Nanooptics

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### 5.262 Course: Theoretical Nanooptics (Minor) [T-PHYS-106311]

**Responsible:** Prof. Dr. Markus Garst  
Prof. Dr. Carsten Rockstuhl  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-103177 - Theoretical Nanooptics (Minor)

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### 5.263 Course: Theoretical Optics [T-PHYS-104578]

**Responsible:** PD Dr. Boris Narozhnyy  
Prof. Dr. Carsten Rockstuhl  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102277 - Theoretical Optics

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**Prerequisites**

none
5.264 Course: Theoretical Optics - Unit [T-PHYS-102305]

**Responsible:** PD Dr. Boris Narozhny
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102279 - Theoretical Optics (Minor)

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**Prerequisites**

none
5.265 Course: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises [T-PHYS-102544]

**Responsible:** Prof. Dr. Gudrun Heinrich
Prof. Dr. Kirill Melnikov
Prof. Dr. Milada Margarete Mühlleitner
Prof. Dr. Ulrich Nierste
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102033 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises

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**Prerequisites**

none
5 COURSES Course: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) [T-PHYS-102540]

5.266 Course: Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor) [T-PHYS-102540]

**Responsible:**
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner
- Prof. Dr. Ulrich Nierste
- Prof. Dr. Matthias Steinhauser

**Organisation:**
KIT Department of Physics

**Part of:**
M-PHYS-102037 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, with Exercises (Minor)

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**Legend:**
- Online,
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- On-Site,
- Cancelled

**Prerequisites**
none
### Course: Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises [T-PHYS-102546]

**Responsible:**
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner
- Prof. Dr. Ulrich Nierste
- Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102035 - Theoretical Particle Physics I, Fundamentals and Advanced Topics, without Exercises

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**Prerequisites**

none
5.268 Course: Theoretical Particle Physics I, Fundamentals, with Exercises [T-PHYS-102545]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102034 - Theoretical Particle Physics I, Fundamentals, with Exercises

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**Prerequisites**

none
5.269 Course: Theoretical Particle Physics I, Fundamentals, with Exercises (Minor) [T-PHYS-102541]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102038 - Theoretical Particle Physics I, Fundamentals, with Exercises (Minor)

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**Legend:** 🖥 Online, Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**
none
5.270 Course: Theoretical Particle Physics I, Fundamentals, without Exercises [T-PHYS-102547]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  
Prof. Dr. Ulrich Nierste  
Prof. Dr. Matthias Steinhauser

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102036 - Theoretical Particle Physics I, Fundamentals, without Exercises

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Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**

none
# 5.271 Course: Theoretical Particle Physics II, with Exercises [T-PHYS-102552]

**Responsible:**
- Prof. Dr. Gudrun Heinrich
- Prof. Dr. Kirill Melnikov
- Prof. Dr. Milada Margarete Mühlleitner

**Organisation:**
- KIT Department of Physics

**Part of:**
- M-PHYS-102046 - Theoretical Particle Physics II, with Exercises

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣️ On-Site, ✗ Cancelled

**Prerequisites**
none
### 5.272 Course: Theoretical Particle Physics II, with Exercises (Minor) [T-PHYS-102548]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102044 - Theoretical Particle Physics II, with Exercises (Minor)

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Legend: 🖥 Online, ⚪ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled

**Prerequisites**

none
### 5.273 Course: Theoretical Particle Physics II, without Exercises [T-PHYS-102554]

**Responsible:** Prof. Dr. Gudrun Heinrich  
Prof. Dr. Kirill Melnikov  
Prof. Dr. Milada Margarete Mühlleitner  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-102048 - Theoretical Particle Physics II, without Exercises  

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Legend: 🖥 Online, 🌍 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled

**Prerequisites**
none
# 5.274 Course: Theoretical Quantum Optics [T-PHYS-110303]

**Responsible:** Prof. Dr. Anja Metelmann  
Prof. Dr. Carsten Rockstuhl  

**Organisation:** KIT Department of Physics  
Part of: M-PHYS-105094 - Theoretical Quantum Optics

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5.275 Course: Theoretical Quantum Optics (Minor) [T-PHYS-110884]

**Responsible:** Prof. Dr. Anja Metelmann  
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105395 - Theoretical Quantum Optics (Minor)

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## 5.277 Course: Theory and Applications of Quantum Machines (Minor) [T-PHYS-112019]

**Responsible:** Prof. Dr. Anja Metelmann  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-105943 - Theory and Applications of Quantum Machines (Minor)

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## 5.278 Course: Theory of Magnetism II [T-PHYS-105961]

**Responsible:** PD Dr. Boris Narozhnyy  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102985 - Theory of Magnetism II

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## 5.279 Course: Theory of Magnetism, with Exercises [T-PHYS-110869]

### Responsible
- Prof. Dr. Markus Garst

### Organisation
- KIT Department of Physics

### Part of
- M-PHYS-105381 - Theory of Magnetism, with Exercises

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5.280 Course: Theory of Magnetism, with Exercises (Minor) [T-PHYS-110873]

**Responsible:** Prof. Dr. Markus Garst

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105385 - Theory of Magnetism, with Exercises (Minor)

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## 5.281 Course: Theory of Seismic Waves [T-PHYS-104736]

**Responsible:** Prof. Dr. Thomas Bohlen  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-102367 - Theory of Seismic Waves

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Course: Theory of Seismic Waves (Minor) [T-PHYS-105571]

**Responsible:** Prof. Dr. Thomas Bohlen

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102657 - Theory of Seismic Waves (Minor)

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# 5.283 Course: Theory of Strongly Correlated Electron Systems [T-PHYS-112245]

**Responsible:** PD Dr. Robert Eder  
**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106056 - Theory of Strongly Correlated Electron Systems

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### Course: Topology in Condensed Matter Physics: Fundamentals and Advanced Topics [T-PHYS-113258]

**Responsible:** PD Dr. Igor Gornyi  
Prof. Dr. Alexander Mirlin  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-106586 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics

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Legend: 🖥 Online, 🎤 Blended (On-Site/Online), 🗂 On-Site, ✗ Cancelled
### 5.285 Course: Topology in Condensed Matter Physics: Fundamentals and Advanced Topics (Minor) [T-PHYS-113259]

**Responsible:** PD Dr. Igor Gornyi  
Prof. Dr. Alexander Mirlin

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-106587 - Topology in Condensed Matter Physics: Fundamentals and Advanced Topics (Minor)

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Legend: 🖥 Online, 🛠 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
# 5.286 Course: Topology in Condensed Matter Physics: Fundamentals and Selected Topics [T-PHYS-113260]

**Responsible:** PD Dr. Igor Gornyi  
Prof. Dr. Alexander Mirlin

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-106588 - Topology in Condensed Matter Physics: Fundamentals and Selected Topics

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Legend: 🖥 Online, ☑ Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
5.287 Course: Tropical Meteorology [T-PHYS-111411]

**Responsible:** Prof. Dr. Peter Knippertz  
**Organisation:** KIT Department of Physics  
**Part of:**  
- M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
- M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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**Legend:** 🖥 Online, 🍂 Blended (On-Site/Online), 🗣 On-Site, ⬀ Cancelled

**Competence Certificate**
Students must achieve 50% of the points on the exercise sheets.

**Prerequisites**
None

**Recommendation**
None

**Annotation**
None
Course: Turbulent Diffusion [T-PHYS-111427]

**5.288 Course: Turbulent Diffusion [T-PHYS-111427]**

**Responsible:** Prof. Dr. Corinna Hoose  
Dr. Gholamali Hoshyaripour

**Organisation:** KIT Department of Physics

**Part of:**  
M-PHYS-104577 - Selected Topics in Meteorology (Second Major, graded)  
M-PHYS-104578 - Selected Topics in Meteorology (Minor, ungraded)

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| ST 2021   | 4052081 | Turbulent Diffusion  | 2 SWS | Lecture / 🖥 | Hoshyaripour, Hoose |
| ST 2021   | 4052082 | Exercises to Turbulent Diffusion | 1 SWS | Practice / 🖥 | Hoshyaripour, Hoose, Bruckert |
| ST 2022   | 4052081 | Turbulent Diffusion  | 2 SWS | Lecture / 🗣 | Hoshyaripour, Hoose  |
| ST 2022   | 4052082 | Exercises to Turbulent Diffusion | 1 SWS | Practice / 🗣 | Hoshyaripour, Hoose, Bruckert |
| ST 2023   | 4052081 | Turbulent Diffusion  | 2 SWS | Lecture / 🗣 | Hoshyaripour, Hoose  |
| ST 2023   | 4052082 | Exercises to Turbulent Diffusion | 1 SWS | Practice / 🗣 | Hoshyaripour, Hoose, Chopra |

Legend: 🖥 Online, 🗣 Blended (On-Site/Online), 🗣 On-Site, X Cancelled

**Competence Certificate**

There are 7 exercises with 100 points in total.

To pass the prerequisite students must:

- Obtain at least 50 points from exercises.
- Present and explain at least one of the ICON-ART exercises in the class.

**Prerequisites**

None

**Recommendation**

None

**Annotation**

None
5.289 Course: Wildcard Non-Physics Elective, Module with 1 Brick, 8 CP graded [T-PHYS-104384]

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102091 - Wildcard Non-Physics Elective, Module with 1 Brick

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**Prerequisites**
none
### 5.291 Course: Wildcard Non-Physics Elective, Module with 2 Bricks, 4 CP graded [T-PHYS-106222]

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103129 - Wildcard Non-Physics Elective, Module with 2 Bricks

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**Prerequisites**  
none
Course: Wildcard Non-Physics Elective, Module with 3 Bricks, 2 CP graded [T-PHYS-106225]

Organisation:  KIT Department of Physics
Part of:        M-PHYS-103130 - Wildcard Non-Physics Elective, Module with 3 Bricks

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Prerequisites
none
5.293 Course: Wildcard Non-Physics Elective, Module with 3 Bricks, 3 CP graded [T-PHYS-106224]

Organisation: KIT Department of Physics
Part of: M-PHYS-103130 - Wildcard Non-Physics Elective, Module with 3 Bricks

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Prerequisites
none
### 5.294 Course: Wildcard Non-Physics Elective, Module with 3 Bricks, 3 CP graded [T-PHYS-106223]

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103130 - Wildcard Non-Physics Elective, Module with 3 Bricks

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**Prerequisites**

none
### 5.295 Course: Wildcard Non-Physics Elective, Module with 4 Bricks, 2 CP graded [T-PHYS-106228]

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103131 - Wildcard Non-Physics Elective, Module with 4 Bricks

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**Prerequisites**

none
## 5.296 Course: Wildcard Non-Physics Elective, Module with 4 Bricks, 2 CP graded [T-PHYS-106229]

**Organisation:** KIT Department of Physics  
**Part of:** M-PHYS-103131 - Wildcard Non-Physics Elective, Module with 4 Bricks

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**Prerequisites**
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Course: Wildcard Non-Physics Elective, Module with 4 Bricks, 2 CP graded [T-PHYS-106226]

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103131 - Wildcard Non-Physics Elective, Module with 4 Bricks

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**Prerequisites**

none
5.298 Course: Wildcard Non-Physics Elective, Module with 4 Bricks, 2 CP graded [T-PHYS-106227]

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-103131 - Wildcard Non-Physics Elective, Module with 4 Bricks

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**Prerequisites**

none
## 5.299 Course: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab [T-PHYS-111156]

| Responsible: | Prof. Dr. Gerd Tilo Baumbach  
|             | Dr. Svetoslav Stankov |
| Organisation: | KIT Department of Physics |
| Part of:    | M-PHYS-105555 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab |

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<td>Practice</td>
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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
# 5.300 Course: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor) [T-PHYS-111158]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105557 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, with Exercises and Lab (Minor)

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Legend: 🖥 Online, ☑ Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
5.301 Course: X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab [T-PHYS-111157]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105556 - X-ray Physics I: Scattering, Diffraction & Spectroscopy on Crystals, thin Films and Nanostructures, without Exercises and without Lab

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Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✗ Cancelled
### 5.302 Course: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab [T-PHYS-111159]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov  

**Organisation:** KIT Department of Physics  

**Part of:** M-PHYS-105558 - X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab

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Legend: 🖥 Online, 📚 Blended (On-Site/Online), 🗣 On-Site, ❌ Cancelled
### Course: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab (Minor) [T-PHYS-111161]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105560 - X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, with Exercises and Lab (Minor)

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Legend: 🖥️ Online, ⚽️️ Blended (On-Site/Online), 🗣️ On-Site, ❌ Cancelled
### 5.304 Course: X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, without Exercises and without Lab [T-PHYS-111160]

**Responsible:** Prof. Dr. Gerd Tilo Baumbach  
Dr. Svetoslav Stankov

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-105559 - X-ray Physics II: Optical Coherence, Imaging and Computed Tomography, without Exercises and without Lab

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