# Modules and Courses
## Master of Science in Physics

Version 2016-08-29

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</table>
## 2 List of Modules and Courses

### 2.1 Overview of the Modules

<table>
<thead>
<tr>
<th>List of Modules - Master</th>
<th>Module</th>
<th>Teaching hours (SWS)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental Physics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental Physics</td>
<td>ExPh</td>
<td>3 V + 1 U</td>
<td>6</td>
</tr>
<tr>
<td><em>Summed credit points for courses in Experimental Physics</em></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td><strong>Theoretical Physics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical Physics</td>
<td>ThPh</td>
<td>4 V + 2 U</td>
<td>9</td>
</tr>
<tr>
<td><em>Summed credit points of courses in Theoretical Physics</em></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td><strong>Seminars</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seminar I</td>
<td>Sem</td>
<td>2 S</td>
<td>4</td>
</tr>
<tr>
<td>Seminar II</td>
<td>Sem</td>
<td>2 S</td>
<td>4</td>
</tr>
<tr>
<td><em>Sum credit points for Seminars</em></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td><strong>Lab courses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced laboratory course</td>
<td>P</td>
<td>8 P</td>
<td>10</td>
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<tr>
<td><em>Summed credit points for lab courses</em></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td><strong>Research Phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Phase – Specialization</td>
<td>FoSp</td>
<td>F</td>
<td>15</td>
</tr>
<tr>
<td>Research Phase – Methodological Knowledge</td>
<td>FoMk</td>
<td>F</td>
<td>15</td>
</tr>
<tr>
<td>Research Phase – Master thesis</td>
<td>FoMA</td>
<td>F</td>
<td>30</td>
</tr>
<tr>
<td><em>Summed credit points for Research Phase</em></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td><strong>Elective Modules</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topical Course I</td>
<td>SV</td>
<td>3 V + 1 U</td>
<td>6</td>
</tr>
<tr>
<td>Topical Course II</td>
<td>SV</td>
<td>3-4 V + 1-2 U</td>
<td>6-9</td>
</tr>
<tr>
<td>Advanced Course</td>
<td>VV</td>
<td>3 V + 1 U</td>
<td>6</td>
</tr>
<tr>
<td>Research Module</td>
<td>FoM</td>
<td>4 SWS</td>
<td>6</td>
</tr>
<tr>
<td><em>To choose:</em></td>
<td></td>
<td></td>
<td>18-12</td>
</tr>
<tr>
<td><strong>Subsidiary Subject</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>To choose:</em></td>
<td></td>
<td></td>
<td>9-15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>120</td>
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</table>
## 2.2 Topical Courses – List of Courses

<table>
<thead>
<tr>
<th>Topical Courses – course list</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condensed Matter Physics</strong></td>
</tr>
<tr>
<td>Selected Topics in Condensed Matter Physics</td>
</tr>
<tr>
<td>Modern Experimental Methods in Condensed Matter Physics</td>
</tr>
<tr>
<td>Materials Science</td>
</tr>
<tr>
<td>Introduction to Condensed Matter Theory</td>
</tr>
<tr>
<td>Selected Chapters of Condensed Matter Theory</td>
</tr>
<tr>
<td>Theory of Soft Matter I</td>
</tr>
<tr>
<td>Computer Simulations in Statistical Physics</td>
</tr>
<tr>
<td>Modern Computational Techniques in Condensed/Soft Matter Physics</td>
</tr>
<tr>
<td><strong>Quantum, Atomic and Neutron Physics</strong></td>
</tr>
<tr>
<td>Quantum Optics (Q-Ex-1)</td>
</tr>
<tr>
<td>Photonics (Q-Ex-2)</td>
</tr>
<tr>
<td>Quantum Information (Q-Ex-3)</td>
</tr>
<tr>
<td>Precision Fundamental Physics (Q-Ex-4)</td>
</tr>
<tr>
<td><strong>Nuclear and Particle Physics</strong></td>
</tr>
<tr>
<td>Statistics, Data Analysis and Simulation</td>
</tr>
<tr>
<td>Particle Detectors</td>
</tr>
<tr>
<td>Accelerator Physics</td>
</tr>
<tr>
<td>Particle Physics</td>
</tr>
<tr>
<td>Astroparticle Physics</td>
</tr>
<tr>
<td>Cosmology and General Relativity</td>
</tr>
<tr>
<td>Symmetries in Physics</td>
</tr>
<tr>
<td>Modern Methods in Theoretical High Energy, Particle and Nuclear Physics</td>
</tr>
<tr>
<td>Theoretical Particle Physics</td>
</tr>
<tr>
<td>Introduction to Lattice Gauge Theory</td>
</tr>
<tr>
<td>Introduction to String Theory</td>
</tr>
<tr>
<td>Effective Field Theories</td>
</tr>
<tr>
<td>Theoretical Astroparticle Physics</td>
</tr>
<tr>
<td>Amplitudes and Precision Physics at the LHC</td>
</tr>
<tr>
<td>Functional Methods and Exact Renormalization Group</td>
</tr>
</tbody>
</table>
### 2.3 Advanced Courses – List of Courses

<table>
<thead>
<tr>
<th>Advanced Courses – course list</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condensed Matter Physics</strong></td>
</tr>
<tr>
<td>Selected Topics in Condensed Matter Physics</td>
</tr>
<tr>
<td>Modern Experimental Methods in Condensed Matter Physics</td>
</tr>
<tr>
<td>Materials Science</td>
</tr>
<tr>
<td>Introduction to Condensed Matter Theory</td>
</tr>
<tr>
<td>Selected Chapters of Condensed Matter Theory</td>
</tr>
<tr>
<td>Theory of Soft Matter I</td>
</tr>
<tr>
<td>Computer Simulations in Statistical Physics</td>
</tr>
<tr>
<td>Modern Computational Techniques in Condensed/Soft Matter Physics</td>
</tr>
<tr>
<td>Theory of Soft Matter II</td>
</tr>
<tr>
<td><strong>Quantum, Atomic and Neutron Physics</strong></td>
</tr>
<tr>
<td>Quantum Optics (Q-Ex-1)</td>
</tr>
<tr>
<td>Photonics (Q-Ex-2)</td>
</tr>
<tr>
<td>Quantum Information (Q-Ex-3)</td>
</tr>
<tr>
<td>Precision Fundamental Physics (Q-Ex-4)</td>
</tr>
<tr>
<td><strong>Nuclear and Particle Physics</strong></td>
</tr>
<tr>
<td>Statistics, Data analysis and Simulation</td>
</tr>
<tr>
<td>Particle Detectors</td>
</tr>
<tr>
<td>Particle Physics</td>
</tr>
<tr>
<td>Astroparticle Physics</td>
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<tr>
<td>Cosmology and General Relativity</td>
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<tr>
<td>Symmetries in Physics</td>
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<tr>
<td>Modern Methods in Theoretical High Energy, Particle and Nuclear Physics</td>
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<tr>
<td>Theoretical Particle Physics</td>
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<tr>
<td>Introduction to Lattice Gauge Theory</td>
</tr>
<tr>
<td>Introduction to String Theory</td>
</tr>
<tr>
<td>Effective Field Theories</td>
</tr>
<tr>
<td>Theoretical Astroparticle Physics</td>
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<tr>
<td>Amplitudes and Precision Physics at the LHC</td>
</tr>
<tr>
<td>Functional Methods and Exact Renormalization Group</td>
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<tr>
<td>Advanced Particle Physics</td>
</tr>
<tr>
<td>Advanced Chapters on Subatomic Physics</td>
</tr>
<tr>
<td>Advanced Astroparticle- and Astrophysics</td>
</tr>
<tr>
<td>Advanced Accelerator Physics</td>
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## 2.4 Subsidiary Subjects

<table>
<thead>
<tr>
<th>Subsidiary Subject</th>
<th>SWS</th>
<th>CP</th>
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<tbody>
<tr>
<td><strong>Chemistry</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Chemistry</td>
<td>2V + 1Ü + 5P</td>
<td>9</td>
</tr>
<tr>
<td>Nuclear Chemistry (with 1 additional advanced lecture)</td>
<td>4V + 1Ü + 5P</td>
<td>12</td>
</tr>
<tr>
<td>Nuclear Chemistry (with 2 additional advanced lectures)</td>
<td>6V + 1Ü + 5P</td>
<td>15</td>
</tr>
<tr>
<td>Introduction in Theoretical Chemistry</td>
<td>4V + 1Ü + 5P</td>
<td>9</td>
</tr>
<tr>
<td>Theoretical Chemistry</td>
<td>4V + 2Ü + 10P</td>
<td>12</td>
</tr>
<tr>
<td><strong>Computer Science</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer Science I</td>
<td>2V + 2Ü + 2P</td>
<td>9</td>
</tr>
<tr>
<td>Computer Science II</td>
<td>4V + 4Ü</td>
<td>12</td>
</tr>
<tr>
<td>Computer Science III</td>
<td>4V + 4Ü + 2P</td>
<td>15</td>
</tr>
<tr>
<td><strong>Economics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International Economics &amp; Public Policy</td>
<td>6V+Ü</td>
<td>12</td>
</tr>
<tr>
<td>Finance &amp; Accounting</td>
<td>6V+Ü</td>
<td>12</td>
</tr>
<tr>
<td>Marketing, Management &amp; Operations</td>
<td>6V+Ü</td>
<td>12</td>
</tr>
<tr>
<td><strong>History of Natural Science</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>History of Natural Science II</td>
<td>2S + 2P</td>
<td>9</td>
</tr>
<tr>
<td><strong>Mathematics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional Analysis</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Functional Analysis (with Functional Analysis II)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Partial differential equations</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Partial differential equations (with partial differential equations II)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Fundamentals in stochastics</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Fundamentals in stochastics (with stochastics I)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Stochastics I</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Stochastics I (with stochastics II)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Basic numerics</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Basic numerics (with numerical methods of ordinary diff. equations)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Numerics of differential equations</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Numerics of differential equations (with partial diff. equations)</td>
<td>8V + 2Ü</td>
<td>15</td>
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<tr>
<td>Algebra</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Algebra (with lecture „Fields, Rings, Modules”)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Topology</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Topology (with lecture „Algebraic curves and Riemannian surfaces”)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td>Computer algebra</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Computer algebra (with Number Theory)</td>
<td>8V + 2Ü</td>
<td>15</td>
</tr>
<tr>
<td><strong>Meteorology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamics of the Atmosphere</td>
<td>4V + 3Ü</td>
<td>9</td>
</tr>
<tr>
<td>Atmospheric Modeling</td>
<td>6V + 4Ü</td>
<td>14</td>
</tr>
<tr>
<td>Atmospheric Radiation</td>
<td>4V + 2Ü</td>
<td>9</td>
</tr>
<tr>
<td>Atmospheric Dynamics</td>
<td>4V + 3Ü + 2P</td>
<td>11</td>
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<tr>
<td><strong>Philosophy</strong></td>
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<tr>
<td>Modern Philosophy</td>
<td>6S</td>
<td>15</td>
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<tr>
<td><strong>Interdisciplinary Courses</strong></td>
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<td></td>
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<tr>
<td>History of Natural Science I</td>
<td>3V</td>
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<tr>
<td>History of Natural Science II</td>
<td>3V</td>
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</table>
3 IMPORTANT REMARKS

3.1 GENERAL REMARKS

1) Within the Master of Science in Physics studies, a minimum of 120 credit points (CP) must be obtained. If the number of credit points is exceeded by more than 6 CP, the study advisor has to be contacted to discuss the situation.

2) Before completion of the master studies either
   - all three experimental physics courses (Ex-5a, Ex-5b, Ex-5c) and 5 course lectures in theoretical physics
   - or at least two of the three experimental physics courses and 6 course lectures in theoretical physics
   have to be completed successfully. In case only one of the experimental physics courses was part of the bachelor studies a corresponding requirement will be issued at the time of admission to the master studies.

3) Within the subsidiary subject at least 9 credit points have to be obtained. On request, subsidiary subjects not listed in this document, may be chosen among courses given at the Johannes Gutenberg-Universität Mainz, the TU Darmstadt or the Goethe-Universität Frankfurt. Please consult the chair of the examination committee before submitting such a request. While many subsidiary subjects will only be given in German, it is worth asking the docent to provide the lectures in English if there is a need.

4) The 6 credit points from the module “Advanced Lectures” can be replaced with 15 CP instead of 9 CP in the subsidiary subject.

5) In case all three experimental physics lectures (Ex-5a, Ex-5b, Ex-5c) were completed successfully before the start of the master studies, an additional advanced course has to be taken.

6) Equivalent courses taken at other universities may be recognised with the credit points awarded for the corresponding course in Mainz. Moderate additional requirements may be imposed.

7) Upon request, the second course of the module “Topical Courses I/II” (Spezialvorlesung I/II) may be replaced with a 4 hour course lecture in theoretical physics.

8) Each course in the module “Topical Courses I/II” can be chosen instead of a course in the module “Advanced lectures” but not vice versa. This choice has to be taken at latest at the end of the 3rd enrolment phase through the corresponding enrolment via the module “Topical Courses I/II” or the “Advanced Lectures”.

9) The interdisciplinary course is optional. In addition to the courses listed in this document, also courses from the “Studium Generale” and internships (“summer student programmes”) at large research laboratories may be accepted. Language courses outside of “Studium Generale” or internships in industry or research institutes can only be recognised after consulting the study advisor.

10) The research module is designed for students who wish to take more advanced courses, i.e. from a graduate school. This module may be chosen instead of the module “Advanced Lectures”.


3.2 REMARKS CONCERNING RESEARCH PHASE

1) The research phase of the Master of Science in Physics programme consists of the three modules “Specialization” (3 months, seminar talk without grades, 15 CP), “Methodological Knowledge” (3 months, graded either through a seminar talk or a portfolio of documents representing the work, 15 CP) and “Master’s Thesis” (6 months including a colloquium, 30 CP). These three modules are considered as one unit and have to be completed consecutively within one year.

2) Students are allowed to enrol into the research phase if at most one of the required courses to reach the 60 CP is missing (e.g. the “Advanced Lectures”, one of the two lectures from “Topical Courses I/II” or one of the two seminars). The start of the master thesis is 6 month after the start of the research phase. At this point in time, at least 60 of the required credit points (§6 subparagraph 2) have to be collected.

3) As the module “Specialization” is part of the preparation towards the master’s thesis, it cannot be taken in parallel to the 6 months long Master’s Thesis module.

4) A change of the master’s thesis advisor can only happen once before the start of the module “Methodological Knowledge”.

5) The enrolment into the research phase is processed by the “Studienbüro Physik” with the help of the following form: [http://www.phmi.uni-mainz.de/Dateien/Anmeldeformular_Masterarbeit_Physik.pdf](http://www.phmi.uni-mainz.de/Dateien/Anmeldeformular_Masterarbeit_Physik.pdf). The “Studienbüro” will then take care of the actual enrolment inside Jogustine.

6) A master’s thesis outside the department of physics, mathematics and computer science (08) has to be requested (please submit an informal request at the Studienbüro). The primary evaluation of an external master’s thesis has to be provided by a professor of the department 08.

7) The end date of the master’s thesis may be extended by at most 4 weeks by the chair of the examination committee. For this to happen, the candidate has to submit a justified written request to the “Studienbüro” which has also to be signed by the corresponding thesis advisor.

8) The “Studienbüro” will enter the mark for the module “Methodological Knowledge” into the system at the end of the one-year research phase. The thesis advisors are requested to submit the mark of the module “Methodological Knowledge” when handing in the primary evaluation to the “Studienbüro”.

9) In case the master’s thesis failed, the module can be repeated once. The new subject of the master thesis has to be sufficiently close to the subjects of the modules “Specialization” and “Methodological Knowledge”.


3.3 **Example for Module Sequence**

<table>
<thead>
<tr>
<th>Module Sequence</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4. (WS or SS)</strong> Master Thesis</td>
<td>30 CP</td>
</tr>
<tr>
<td>Thesis: 29 CP</td>
<td></td>
</tr>
<tr>
<td>Colloquium: 1 CP</td>
<td></td>
</tr>
<tr>
<td><strong>3. (SS or WB)</strong> Methodological Knowledge</td>
<td>30 CP</td>
</tr>
<tr>
<td>15 CP</td>
<td></td>
</tr>
<tr>
<td>Specialization</td>
<td></td>
</tr>
<tr>
<td>15 CP</td>
<td></td>
</tr>
<tr>
<td><strong>2. (WS or SS)</strong> Advanced Courses</td>
<td>31 CP</td>
</tr>
<tr>
<td>Topical Course 2</td>
<td></td>
</tr>
<tr>
<td>3 L + 1 E 8 CP</td>
<td></td>
</tr>
<tr>
<td>Laboratory 1</td>
<td></td>
</tr>
<tr>
<td>Laboratory 2</td>
<td></td>
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<tr>
<td>Seminar</td>
<td></td>
</tr>
<tr>
<td>Seminar 2</td>
<td></td>
</tr>
<tr>
<td>2 E 4 CP</td>
<td></td>
</tr>
<tr>
<td>Subsidiary Subject</td>
<td></td>
</tr>
<tr>
<td>Nuclear Chemistry</td>
<td></td>
</tr>
<tr>
<td>5 CP</td>
<td></td>
</tr>
<tr>
<td><strong>1. (SS or WS)</strong> Experimental Physics</td>
<td>29 CP</td>
</tr>
<tr>
<td>Topical Course 1</td>
<td></td>
</tr>
<tr>
<td>3 L + 1 E 8 CR</td>
<td></td>
</tr>
<tr>
<td>Seminar</td>
<td></td>
</tr>
<tr>
<td>Seminar 1</td>
<td></td>
</tr>
<tr>
<td>2 E 4 CR</td>
<td></td>
</tr>
<tr>
<td>Subsidiary Subject</td>
<td></td>
</tr>
<tr>
<td>Nuclear Chemistry</td>
<td></td>
</tr>
<tr>
<td>5 CP</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The hours/week (h/w) are as follows:
- **Experimental Physics:** 39 CP, 19 h/w
- **Theoretical Physics:** 39 CP, 19 h/w
- **Topical Courses:** 39 CP, 19 h/w
- **Advanced Courses:** 39 CP, 19 h/w
- **Research Phase:** 120 CP
- **Advanced Laboratory:** 39 CP, 19 h/w
- **Seminar:** 39 CP, 19 h/w
- **Subsidiary Subject:** 39 CP, 19 h/w

**Sum of credit points and hours/week (h/w):**

- **Total Credit Points:** 120 CP
### 4.1 Experimental Physics

<table>
<thead>
<tr>
<th>Module Experimental Physics: „Atomic and Quantum Physics“</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID number 08.128.050</td>
</tr>
<tr>
<td>----------------------</td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>138 h</td>
</tr>
</tbody>
</table>

2. **Lectures with exercises**

<table>
<thead>
<tr>
<th>„Atomic and Quantum Physics“ (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 SWS/31.5 h</td>
</tr>
</tbody>
</table>

3. **Exercises (WP)**

<table>
<thead>
<tr>
<th>1 SWS/10.5 h</th>
</tr>
</thead>
</table>

2. **Group sizes**

- Lecture: unlimited
- Exercise: 20

3. **Qualification and program goals/Competences**

Students should acquire a
- basic knowledge on the physics of atoms, molecules and quanta,
- understand the structure of atoms and simple molecules as well as their interactions with quanta,
- apply quantum mechanical approaches to practical examples and thus deepen their understanding,
- achieve insights into modern experimental techniques in atomic physics, spectroscopy and the manipulation of quantum systems by coherent radiation

4. **Course content**

Profound introduction to the experimental quantum physics of atoms and molecules and their interaction with light. The strong experiment-theory interlink in this field is detailed and can be supported by the embedding of guest lectures.

The lectures cover the following set of topics:
- relativistic effects and Dirac equation for the hydrogen atom, influences of the atomic nucleus, atoms in external fields
- atoms in laser fields – light-atom interaction, coherent and spontaneous scattering processes
- many electron systems, fundamentals of laser spectroscopy on atoms and molecules;
- manipulation and trapping of neutral atoms, molecules and ions, Ramsey method, atomic clocks,
- as well as Bose Einstein condensation

5. **Applicable to the following programs**

- BSc. physics, MSc. physics, MSc. mathematics

6. **Recommended prerequisites**

Theoretical Physics 3 „Quantum Mechanics“, Experimental Physics 3 “Waves and Quantum Mechanics”

7. **Entry requirements**

8. **Mode and duration of examinations**

- 8.1. Active participation
- 8.2. Course achievements
- 8.3. Module examination

Written exam (120-180 Min.) or oral examination (30 Min.)

9. **Weighting of the achievement in the overall grade**

6/120
Module Experimental Physics: „Atomic and Quantum Physics“

10. Frequency of the module offering
   Winter semester

11. Persons responsible for this module and full-time lecturers
   Responsible: Prof. Dr. F. Schmidt-Kaler, Prof. Dr. K. Wendt
   Lecturers: All lecturers in experimental physics

12. Auxiliary Information
   Course language:
   - German or English on request
   Literature:
   - Physics of Atoms and Molecules, B.H. Bransden & C.J. Joachain
   - Atom- und Quantenphysik, H. Haken & H.C. Wolf
   - Experimental Physics 3: Atoms, Molecules and Solid State Physics, Demtröder
   - specialized literature

Module Experimental Physics: „Nuclear and Particle Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.055</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
   Lecture with exercises
   „Kern- und Elementarteilchenphysik“ (WP)
   Lecture (WP) 138 h 6 LP
   Exercises (WP) 3 SWS/31.5 h 1 SWS/10.5 h

2. Group sizes
   Lecture: unlimited
   Exercise: 20

3. Qualification and program goals/Competences
   Upon completion of the course, students should have gained
   - a basic understanding of the physics of elementary building blocks of matter (quarks and leptons) and their
     compound systems (mesons, baryons and nucleons) as well as an understanding of their fundamental and
     effective interactions as well as
   - an exemplary understanding of the importance of scattering reactions, symmetries, model building in complex
     systems and perturbative calculations (Feynman diagrams).
   As a result of the course, students should comprehend the current scientific view of the structure of matter as well as
   key experiments.

4. Course content
   The course covers the following subjects:
   - properties, stability, structure, shape, and excitations of nuclei as well as the forces between nucleons,
   - elastic, inelastic and deep-inelastic scattering reactions,
   - strong, weak and electro-weak interactions and an introduction to the standard model of particle physics,
   - ep, pp und e⁺e⁻ reactions,
   - bound systems (quarkonia, mesons, baryons),
   - essential symmetries used to classify particles and important selection rules governing particle reactions.

5. Applicable to the following programs
   BSc. Physics, MSc. Physics, MSc. Mathematics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations
   8.1. Active participation
Module Experimental Physics: „Nuclear and Particle Physics“

successful completion of the exercises

8.2. Course achievements

8.3. Module examination

Written exam (120-180 Min.) or oral examination (30 Min.)

9. Weighting of the achievement in the overall grade

6/120

10. Frequency of the module offering

Every semester

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

Module responsibilities: Prof. Dr. L. Köpke, Prof. Dr. J. Arends
Lecturers: All lecturers in experimental nuclear and particle physics

12. Auxiliary Information

Course language:
- German or English on request
- Literature: Povh, Rith, Scholz „Teilchen und Kerne“ (DOI: 10.1007/978-3-642-37822-5)
Other books on nuclear and particle physics

Module Experimental Physics: „Condensed Matter Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.060</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

Lectures with exercises
„Condensed Matter Physics“ (WP)

Lectures (WP) 138 h 6 LP

Excercises (WP) 3 SWS/31.5 h

2. Group sizes

Lecture: unlimited
Excercise: 20

3. Qualification and program goals/Competences

The Module „Condensed Matter Physics“ provides the students
- with a substantial knowledge of the interrelation of the different constituents and states of condensed matter and on elementary excitations, their relation to material properties and on their role in complex processes as well as with
- the capability to use the basic elements and concepts of quantum mechanics and statistical mechanics to describe the many body nature of condensed matter phenomena.

The lecture provides a solid foundation for a comprehensive understanding of material science problems and a key to grasp the numerous effects behind technical applications of modern condensed matter physics.

4. Course content

- Processes of structural change: model systems, nucleation and growth, glass transition
- Electrons in solids: single electron models, free electron gas, band model, semi-conductors, specific heat of metals, anharmonic effects, heat conduction
- Correlated electrons: magnetism, superconductivity, heavy fermions
- Applications: surfaces, spectroscopic methods

5. Applicable to the following programs

BSc. Physics, MSc. Physics, MSc. Mathematics

6. Recommended prerequisites
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Module Experimental Physics: „Condensed Matter Physics“</strong></td>
<td></td>
</tr>
<tr>
<td><strong>7.</strong> Entry requirements</td>
<td></td>
</tr>
<tr>
<td><strong>8.</strong> Mode and duration of examinations</td>
<td></td>
</tr>
<tr>
<td>8.1. Active participation</td>
<td>successful completion of the exercises</td>
</tr>
<tr>
<td><strong>8.2. Course achievements</strong></td>
<td></td>
</tr>
<tr>
<td><strong>8.3. Module examination</strong></td>
<td>Written exam (120-180 Min.) or oral examination (30 Min.)</td>
</tr>
<tr>
<td><strong>9.</strong> Weighting of the achievement in the overall grade</td>
<td>6/120</td>
</tr>
<tr>
<td><strong>10.</strong> Frequency of the module offering</td>
<td>Every semester</td>
</tr>
<tr>
<td><strong>11.</strong> Persons responsible for this module and full-time lecturers</td>
<td>Responsible: Prof. Dr. Th. Palberg, Prof. Dr. G. Schönhense Lecturers: All lecturers in experimental condensed matter physics</td>
</tr>
<tr>
<td><strong>12.</strong> Auxiliary Information</td>
<td>Course language: German or English on request Literature:</td>
</tr>
</tbody>
</table>
### Module Theoretical Physics: „Advanced Quantum Mechanics“

<table>
<thead>
<tr>
<th>ID number 08.128.151</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>270 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>9 LP</td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**

- **Lectures with exercises „Advanced Quantum Mechanics“ (WP)**
  - Contact time: 207 h
  - Credit Points: 9 LP

- **Lectures (WP)**
  - 4 SWS/42 h

- **Exercises (WP)**
  - 2 SWS/21 h

2. **Group sizes**

- Lecture: unlimited
- Exercice: 20

3. **Qualification and program goals/Competences**

   The aim of this course is to get the students acquainted with advanced methods of quantum mechanics. In this context, the methods of second quantization and relativistic quantum mechanics are discussed, thereby guiding students towards current research topics. During the last third part of the course, the lecturers will focus on a selected topic of their choice.

4. **Course content**

   - **Many-particle systems:** Many-particle Schrödinger equation, second quantization for bosons and fermions, Fock space, creation and annihilation operators, Hartree-Fock approximation, interaction of non-relativistic matter with the radiation field (e.g. emission and absorption of photons by atoms, scattering of photons on atoms).
   - **Relativistic quantum mechanics:** Klein-Gordon equation and Dirac equation with associated Lagrange density, interaction with radiation field, applications e.g. hydrogen atom.
   - Additional in-depth topics may vary according to the lecturer. Possible topics are: Introduction to the path integral formalism, advanced group theory (Poincare group, representation theory, Wigner-Eckart theorem, spinor representations), quantum optics, examples from many-particle physics.

5. **Applicable to the following programs**

   - BSc. Physics, MSc. Physics

6. **Recommended prerequisites**

7. **Entry requirements**

8. **Mode and duration of examinations**

   - **8.1. Active participation**
   - **8.2. Course achievements**
   - **8.3. Module examination**

     Written exam (120-180 Min.) or oral examination (30 Min.)

9. **Weighting of the achievement in the overall grade**

   - 9/120

10. **Frequency of the module offering**

    - Every semester

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

    - Responsible: Prof. Dr. S. Weinzierl
    - Lecturers: All lecturers in theoretical physics

12. **Auxiliary Information**
**Module Theoretical Physics: „Advanced Quantum Mechanics“**

<table>
<thead>
<tr>
<th>Course language:</th>
<th>- German or English on request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature:</td>
<td>Text books on theoretical physics, e.g. F. Schwabl, Advanced Quantum Mechanics, J.J. Sakurai, Advanced Quantum Mechanics, J.D. Bjorken and S.D. Drell, Relativistic Quantum Mechanics</td>
</tr>
</tbody>
</table>
## Module Theoretical Physics: „Relativistic Quantum Field Theory“

<table>
<thead>
<tr>
<th>ID number 08.128.165</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>270 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>9 LP</td>
</tr>
</tbody>
</table>

### 1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with exercises</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>„Relativistic Quantum Field Theory“ (WP)</td>
<td>207 h</td>
<td>9 LP</td>
<td></td>
</tr>
<tr>
<td>Lectures (WP)</td>
<td>4 SWS/42 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercises (WP)</td>
<td>2 SWS/21 h</td>
<td></td>
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</tbody>
</table>

### 2. Group sizes

- Lecture: unlimited
- Exercise: 20

### 3. Qualification and program goals/Competences

Relativistic quantum field theory constitutes the foundation of the Standard Model of particle physics and is essential for an understanding of modern particle and hadron physics. This lecture aims at theoretical interested students, which would like to start in the field of particle and hadron physics. The lecture provides the basic tools of relativistic quantum field theory. Subsequent specialized lectures may build on these basic tools.

### 4. Course content

- Path integrals, Grassmann numbers, quantization of the Klein-Gordon field, Dirac, Maxwell and interacting fields, Wick's theorem, Feynman rules, cross sections, S-matrix, LSZ-reduction formula, basics and outlook of non-abelian gauge theories and spontaneous symmetry breaking.

### 5. Applicable to the following programs

- MSc. Physcs

### 6. Recommended prerequisites

- Entry requirements

### 8. Mode and duration of examinations

8.1. Active participation

- successful completion of the exercises

8.2. Course achievements

8.3. Module examination

- Written exam (120-180 Min.) or oral examination (30 Min.)

### 9. Weighting of the achievement in the overall grade

- 9/120

### 10. Frequency of the module offering

- Every semester

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

- Responsible: Prof. Dr. S. Weinzierl
- Lecturers: All lecturers in theoretical physics

### 12. Auxiliary Information

- Course language: English
- Literature: Text books on theoretical physics, e.g.
  - M. E. Peskin and D.V. Schroeder, An Introduction to Quantum Field Theory
  - M.D. Schwartz, Quantum Field Theory and the Standard Model
# Module Theoretical Physics: „Advanced Statistical Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.170</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>270 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>9 LP</td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Lectures with exercises**

<table>
<thead>
<tr>
<th>„Advanced Statistical Physics“ (WP)</th>
<th>207 h</th>
<th>9 LP</th>
</tr>
</thead>
</table>

**Lectures (WP)**

<table>
<thead>
<tr>
<th>4 SWS/42 h</th>
</tr>
</thead>
</table>

**Exercises (WP)**

<table>
<thead>
<tr>
<th>2 SWS/21 h</th>
</tr>
</thead>
</table>

2. **Group sizes**

- Lecture: unlimited
- Exercise: 20

3. **Qualification and program goals/Competences**

Students will get to know advanced concepts and applications of statistical physics. They will learn central concepts on how to describe systems and materials whose behavior is dominated by large fluctuations, such as liquids in general, many plastics, most biomaterials, but also systems beyond the scope of natural sciences (e.g. in finance). The focus lies on general overarching principles, such as symmetries, cooperative processes and phase transitions, scales and scale free behavior, as well as coarse-graining. Specific examples will be selected based on the current research topics in Mainz and will to a large extent be related to soft matter.

4. **Course content**

1) Basic concepts in a statistical description of complex systems at equilibrium and non-equilibrium, linear response and transport, stochastic processes, structure and scattering;

2) Modeling concepts, symmetries and conservation laws, coarse-graining concepts (reduction of degrees of freedom), Newtonian dynamics, Brownian dynamics, hydrodynamics at low Reynolds numbers, simulation methods;

3) Phase transitions, mean-field approaches, Landau theory, fluctuations and critical exponents, scale invariance and renormalization, and (possibly) basic concepts of statistical field theory;

4) Concepts of polymer physics such as polymer models, ideal and real chains, scale invariance and “blob” concept, polymer dynamics (Rouse, Zimm, Reptation), polymer mixtures and Flory Huggins theory, and (possibly) basic concepts of polymer field theory.

Other topics are selected based on the preferences of the lecturers. Possibilities are: Non-equilibrium thermodynamics, stochastic thermodynamics, disordered systems and glasses, statistical physics of complex soft matter (e.g., self assembling systems, membranes, liquid crystals, colloidal systems, charged systems, entangled systems, biomolecules, biomaterials), as well as interdisciplinary applications of statistical physics, e.g., in finance.

5. **Applicable to the following programs**

MSc. Physics

6. **Recommended prerequisites**

Theory 1-4

7. **Entry requirements**

8. **Mode and duration of examinations**

8.1. **Active participation**

Successful completion of the exercises

8.2. **Course achievements**

8.3. **Module examination**

Written exam (120-180 Min.) or oral examination (30 Min.)

9. **Weighting of the achievement in the overall grade**

9/120

10. **Frequency of the module offering**

At least once per year

11. **Persons responsible for this module and full-time lecturers**
## Module Theoretical Physics: "Advanced Statistical Physics"

<table>
<thead>
<tr>
<th>Responsible: Prof. Dr. F. Schmid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturers: All lecturers in theoretical physics</td>
</tr>
</tbody>
</table>

### Auxiliary Information

- **Course language:** German or English on request
- **Literature:**
  - Chaikin/Lubensky: Principles of Condensed Matter Physics
  - Plischke/Bergersen: Equilibrium Statistical Physics
  - Landau-Lifshitz: Theoretical physics V und IX
  - Goldenfeld: Lectures on phase transitions and the renormalization group
  - Paul/Baschnagel: Stochastic processes
  - Risken: The Fokker-Planck equation
  - Guyon, Hulin, Petit, Mitesu: Physical Hydrodynamics
  - de Gennes: Scaling Concepts in Polymer Physics
  - Doi/Edwards: The Theory of Polymer Dynamics
  - Grosberg/Khokhlov: Statistical Mechanics of Macromolecules
  - Rubinstein/Colby: Polymer Physics

## Module Theoretical Physics: "Theoretical quantum optics and many body physics"

<table>
<thead>
<tr>
<th>ID number 08.128.175</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>9 LP</td>
<td></td>
</tr>
</tbody>
</table>

### Courses/Teaching methods

- **Lecture with excercises**
  - "Theoretical quantum optics and many body physics"
  - Contact time: 138 h
  - Self-study

- **Lectures (WP)**
  - 4 SWS/31.5 h

- **Excercises (WP)**
  - 2 SWS/10.5 h

### Group sizes

- Lecture: unlimited
- Excercise: 20

### Qualification and program goals/Competences

After this course, the students should amongst others:
- be able to apply advanced methods of Theoretical Quantum Physics,
- be familiar with the interpretation, examination and formulation of quantum field theories,
- have a deeper understanding of the most important phenomena and models of many-particle theory and theoretical quantum optics

This is to create a solid basis to deal with research-related topics in the field.

### Course content

The course offers a profound theoretical introduction to the overlapping fields of theoretical many particle physics, quantum optics and solid state quantum theory. It also offers an introduction to quantum information, ultracold gases and photonics. The strong theory-experiment interlink in this research area is supported by the possible embedding of focused experimental guest lectures into the course.

Selection of topics:
- Introduction: 1-particle and many-body Schrödinger equation, spin and its physical consequences, fermions and bosons, Green functions
- Quantum many-body theory: creation and annihilation operators, observables, quantum field theory, applications (interacting Fermi gas, interacting Bose gas, ultra-cold quantum gases, $^4$He), coherent states, path integrals
- Quantum theory of the electromagnetic field: classical Maxwell field, Lagrange and Hamilton formalisms, quantization of the electromagnetic field, interaction of the electromagnetic field with matter, Casimir effect, Rayleigh and Thomson scattering, Raman effect
- Quantum optics: photon statistics, photon antibunching, coherent states, squeezed light, number states, atoms in cavities, quantum information (cryptography, computing, teleportation)
- Methods and models of quantum optics: coherent interactions, Jaynes-Cummings model, operators, operator identities and basis states, quantum statistics, characteristic functions, quasi-probability distributions, dissipative processes, spin-boson model, master equations, dressed states.

### Applicable to the following programs

- MSc. Physics
Module Theoretical Physics: „Theoretical quantum optics and many body physics“

18. Recommended prerequisites
   Knowledge at the level of the courses Theoretical Physics 1-5 of the Bachelor's degree program

19. Entry requirements
   Bachelor sc. degree

20. Mode and duration of examinations
   - **8.1. Active participation**
     successful completion of the exercises
   - **8.2. Course achievements**
   - **8.3. Module examination**
     Written exam (120-180 Min.) or oral examination (30 Min.)

21. Weighting of the achievement in the overall grade
   9/120

22. Frequency of the module offering
   Annually in winter term

23. Persons responsible for this module and full-time lecturers
   Responsible: Prof. Dr. P. van Dongen, Prof. Dr. P. van Loock
   Lecturers: All lecturers in theoretical "hard" condensed matter physics and in theoretical quantum optics

24. Auxiliary Informations
   Course language: German or English
   Literature:
Module Advanced Laboratory Course

<table>
<thead>
<tr>
<th>ID number M.08.128.620</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>10 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

   Contact time | Self-study | Credit Points |
   4 SWS/42 h   | 108 h      | 5 LP           |
   a) Advanced Laboratory Part 1 (P) |
   b) Advanced Laboratory Part 2 (P) |

2. Group sizes

   Typical 2 student working on the same laboratory experiment

3. Qualification and program goals/Competences

   The students are supposed to deepen advanced work in experimental and numerical-theoretical fields of physics. This is practiced by carrying out challenging experiments in two-person teams, extending over several days under supervision of experienced assistants. Usually complex data acquisition systems and computer-based analysis methods are used. Compared to the bachelor advanced laboratory course here is more emphasis on independent work.

4. Course content

   In both parts 1 and 2, experiments will be performed summing up to a total of 10 laboratory days. 
   Part 1: 2-3 advanced two-day experiments from the fields: atomic physics, quantum optics, nuclear physics, elementary particle physics, solid state physics, detectors and particle detection, and atmospheric physics. 
   Part 2: the remaining time may be filled with existing experiments or with extended projects in an experimental or theoretical work group.

5. Applicable to the following programs

   MSc. Physics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations

   8.1. Active participation

   8.2. Course achievements

   8.3. Module examination

   Portfolio of experiments from part 1 and part 2

9. Weighting of the achievement in the overall grade

   10/120

10. Frequency of the module offering

    Every semester

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

    Responsible: Prof. Dr. H.-J. Arends
    Lecturers: All lecturers in physics

12. Auxiliary Information

    Course language:
      - German or English
    Literature: Manuals of experiments with special references
Module Seminars

<table>
<thead>
<tr>
<th>ID number M.08.128.630</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 h</td>
<td>2 Semesters</td>
<td>1. Semester</td>
<td>8 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

<table>
<thead>
<tr>
<th></th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Group sizes

3. Qualification and program goals/Competences

The goal of the seminars is to learn and practice giving presentations on topical physics areas. Specifically, the students should
- learn and practice presentation techniques and
- to discuss the physics contents.
Seminar 2 should include a deepened examination and discussion of up-to-date questions in physics research.

4. Course content

a) Student presentations of topics from a broad spectrum of current experimental and theoretical physics.
b) Student presentations on up-to-date topics relevant to the experimental or theoretical working groups of the physics institutes. Usually, several subjects will be offered to choose from with focus on atomic physics, condensed matter, nuclear and particle physics.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation
 Attendance of all seminars

8.2. Course achievements

8.3. Module examination

The students’s presentations are graded both for seminar 1 and seminar 2

9. Weighting of the achievement in the overall grade

8/120

10. Frequency of the module offering

Every semester

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

Responsible: Prof. Dr. H.-J. Arends
Lecturers: All lecturers in physics

12. Auxiliary Information

Course language:
- German or English

Literature:
### Module Topical Courses: „Selected topics in Condensed Matter Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.720</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**

<table>
<thead>
<tr>
<th>Lectures with exercises „Selected topics in Condensed Matter Physics“ (WP)</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>138 h</td>
<td></td>
<td>6 LP</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
<th>3 SWS/31.5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises (WP)</td>
<td>1 SWS/10.5 h</td>
</tr>
</tbody>
</table>

2. **Group sizes**

- Lecture: unlimited
- Exercise: 20

3. **Qualification and program goals/Competences**

Students shall be guided towards a selection of special problems in modern Condensed Matter Physics to obtain a solid background when dealing with research related topics. Magnetism and super conductivity emerge through the correlated dynamics of electrons in solids and provide the basis of modern electronics and information technology. Surface Science is essential for an in depth understanding of miniaturized devices as well as for novel diagnostic techniques. Soft Matter shows fascinating structural and dynamic properties and nurtures a rapidly developing field of applications. Its fundamental scientific questions also related to other disciplines like biology, chemistry and medicine. By an depth treatment of one or more of these topics, the course will provide a solid basis for conducting a master thesis in the area of Condensed Matter Physics.

4. **Course content**

Depending on the lecturer, the course will focus on specific topics, such as magnetism, super conductivity, heavy fermions, applied solid state physics, surface science or soft matter physics

5. **Applicable to the following programs**

- MSc. Physics

6. **Recommended prerequisites**

Knowledge of experimental physics on the level of the module Experimental Physics 5c "Physics of Condensed Matter"

7. **Entry requirements**

8. **Mode and duration of examinations**

   8.1. Active participation
   
   successful completion of the exercises
   
   8.2. Course achievements
   
   8.3. Module examination
   
   Common oral examination (30 – 45 Min.) covering two topical courses

9. **Weighting of the achievement in the overall grade**

   6/120

10. **Frequency of the module offering**

    Each summer semester

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

    Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui
    Lecturers: All lecturers in experimental condensed matter physics

12. **Auxiliary Information**
## Module Topical Courses: „Selected topics in Condensed Matter Physics“

**Course language:**
- German or English on request

**Literature:** will be provided by the lecturer

## Module Topical Courses: „Modern Experimental Methods in Condensed Matter Physics“

<table>
<thead>
<tr>
<th>ID number</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
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<tbody>
<tr>
<td>08.128.721</td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</table>

1. **Courses/Teaching methods**

   **Lectures with exercises „Modern experimental methods in Condensed Matter Physics“ (WP)**

   - **Lectures (WP)**
     - 3 SWS/31.5 h
   - **Exercises (WP)**
     - 1 SWS/10.5 h

2. **Group sizes**

   - Lecture: unlimited
   - Exercise: 20

3. **Qualification and program goals/Competences**

   Students shall be guided towards both fundamental facts and special aspects of state-of-the-art experimental methods in material science. The course will therefore present important and state of the art techniques and approaches. Examples may include spectroscopic methods, scattering techniques, scanning probe techniques as well as application related characterization of novel materials, sample preparation and conditioning techniques. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis in Condensed Matter Physics in this or a related area.

4. **Course content**

   Depending on the lecturers, the course will focus on specific topics such as spectroscopic methods, scattering techniques, modern microscopy techniques, scanning probe techniques, synthesis strategies, sample preparation techniques or methods for material characterization under application related conditions.

5. **Applicable to the following programs**

   MSc. Physics

6. **Recommended prerequisites**

   Knowledge of experimental physics on the level of the module Experimental Physics 5c “Physics of condensed matter”

7. **Entry requirements**

8. **Mode and duration of examinations**

   8.1. **Active participation**
   - successful completion of the exercises

   8.2. **Course achievements**

   8.3. **Module examination**
   - Common oral examination (30 – 45 Min.) covering both topical courses

9. **Weighting of the achievement in the overall grade**

   6/120

10. **Frequency of the module offering**

    Every winter semester

11. **Persons responsible for this module and full-time lecturers**
Module Topical Courses: „Modern Experimental Methods in Condensed Matter Physics“

Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui
Lecturers: All lecturers in experimental condensed matter physics

12. Auxiliary Information

Course language:
- German or English on request

Literature:

Module Topical Courses: „Materials Science“

<table>
<thead>
<tr>
<th>ID number</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
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<tbody>
<tr>
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<td>180 h</td>
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<td>1. Semester</td>
<td>6 LP</td>
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</table>

1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with excercises „Materials Science“ (WP)</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures (WP)</td>
<td>138 h</td>
<td>6 LP</td>
<td></td>
</tr>
<tr>
<td>Excercises (WP)</td>
<td>1 SWS/10,5 h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Group sizes

Lecture: unlimited
Excercise: 20

3. Qualification and program goals/Competences

Students shall be guided towards the essential physics of Material Science that is necessary for an understanding of processes in novel materials on the atomic and the nano-scale. Topics of interest covered by the course are, for example, the structure and properties of functional materials, nanomaterials, fluids and soft materials, glasses, functionalized surfaces, formation of and transitions within solids, modern methods of material science, as well as concepts and fundamentals of novel materials including their development and application. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis in Condensed Matter Physics in this or a related area.

4. Course content

Depending on the lecturer, the course will focus on specific topics like e.g. functional materials, nano materials, soft matter materials, glasses, functionalized surfaces, development strategies, characterization methods, phase transitions or materials for specific applications

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Knowledge of Experimental Physics on the level of the Modul Experimentalphysik 5c "Physik kondensierter Materie" of the Bachelor degree programme

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation

successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

9. Weighting of the achievement in the overall grade
Module Topical Courses: „Materials Science“

| 6/120 |

10. Frequency of the module offering

Every semester

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

Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui
Lecturers: All lecturers in experimental condensed matter physics

12. Auxiliary Information

Course language:
- German or English on request

Literature:

Module Topical Courses: „Introduction to Condensed Matter Theory“

<table>
<thead>
<tr>
<th>ID number 08.128.723</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
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<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with exercises</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>„Introduction to Condensed Matter Theory“ (WP)</td>
<td>138 h</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

   Lectures (WP)
   3 SWS/31.5 h

   Exercises (WP)
   1 SWS/10.5 h

2. Group sizes

Lecture: unlimited
Exercise: 20

3. Qualification and program goals/Competences

Building on the introductory courses on quantum mechanics and statistical thermodynamics, the central concepts of the description of crystalline solids shall be discussed. Starting from lattice periodicity and crystal symmetry, concepts like the electronic structure (electrons in a crystal field potential) and elementary excitations (phonons, magnons, plasmons, etc.) and their consequences for the various physical properties of solids at low temperatures are explained, thereby creating a solid basis to deal with research-related topics in the field of condensed matter theory.

4. Course content

Crystal structure, symmetry, the concept "reciprocal lattice", lattice dynamics in the harmonic approximation, relation to the elastic constants, electrons in a crystal field (Bloch wave and Wannier functions, energy bands, etc.), basic concepts of magnetism, magnons, etc. Also, depending on the choice of the lecturer, selected advanced topics (e.g., scattering theory of solids, electron-phonon interaction, plasmons and dielectric response, etc.) are presented.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Knowledge at the level of the courses Theoretical Physics 1-5 of the Bachelor's degree program

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation
successful completion of the exercises

8.2. Course achievements
Module Topical Courses: „Introduction to Condensed Matter Theory“

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

9. Weighting of the achievement in the overall grade
6/120

10. Frequency of the module offering
Every summer semester

11. Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. P. van Dongen
Lecturers: All lecturers in theoretical “hard” condensed matter physics

12. Auxiliary Information
Course language:
- German or English on request

Literature:

Module Topical Courses: „Selected Chapters of Condensed Matter Theory“

<table>
<thead>
<tr>
<th>ID number 08.128.724</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
Lectures with exercises „Selected Chapters of Condensed Matter Theory“ (WP)

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
<th>3 SWS/31.5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises (WP)</td>
<td>1 SWS/10.5 h</td>
</tr>
</tbody>
</table>

2. Group sizes
Lecture: unlimited
Exercice: 20

3. Qualification and program goals/Competences
Building on the foundations of statistical thermodynamics and/or quantum mechanics of many-body systems, the students will be introduced to specific aspects of the theory of quantum many-particle systems ("hard" condensed matter). Topics to be treated may include the theory of correlated fermions, modern static and dynamic phenomena of magnetism, low-dimensional systems, disorder, quantum phase transitions, many-body theory and their numerical methods, the theory of superfluidity and superconductivity, and topological quantum matter. Having completed this course, the student should have achieved a deeper understanding and a research-level specialization of condensed matter theory, which should form a solid foundation to successfully complete a master’s thesis in a related field of physics.

4. Course content
Depending on the lecturer, the lecture may be focused on numerical methods in many-body physics, the theory of correlated fermions, the theory of superconductivity, modern magnetism, or topological systems.

5. Applicable to the following programs
MSc. Physics

6. Recommended prerequisites
Knowledge at the level of the courses Theoretical Physics 1-5 of the bachelor's degree program

7. Entry requirements

8. Mode and duration of examinations
8.1. Active participation
successful completion of the exercises
Module Topical Courses: „Selected Chapters of Condensed Matter Theory“

8.2. Course achievements

8.3. Module examination
Common oral examination (30 – 45 Min.) covering both topical courses

9. Weighting of the achievement in the overall grade
6/120

10. Frequency of the module offering
Every summer semester

11. Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. P. van Dongen
Lecturers: All lecturers in theoretical “hard” condensed matter physics

12. Auxiliary Information
Course language:
- German or English on request
Literature:


<table>
<thead>
<tr>
<th>ID number 08.128.725</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

1. Courses/Teaching methods

Lectures with excercises „Theory of soft matter I“ (WP)
Lectures (WP) 138 h 6 LP
Excercises (WP) 3 SWS/31.5 h

2. Group sizes
Lecture: unlimited
Excercise: 20

3. Qualification and program goals/Competences
The students become acquainted with the statistical description of systems with large fluctuations for the example of various soft matter systems. A special focus lies on general principles that may be applied for different material classes.

4. Course content
General concepts: Modeling, symmetry, and conservation laws, scattering laws, self similarity and scale invariance, mean-field approaches and Landau theories, Brownian dynamics, Critical dynamics;
Structure: Polymers (random walk, self-avoiding walk, blob concept, Flory screening, Flory Huggins theory, Path integral description of polymers, polymer field theory), Membranes (fluid, hexatic and crystalline membranes), Landau-de Gennes theory of liquid crystals;
Dynamics: Polymers (Rouse model), hydrodynamics at low Reynolds numbers, and (possibly) active and nonequilibrium matter.

5. Applicable to the following programs
MSc. Physics

6. Recommended prerequisites
Theory 1-4, in particular Statistical Physics

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation
Successful completion of the exercises

8.2. Course achievements

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

9. Weighting of the achievement in the overall grade
6/120

10. Frequency of the module offering
Upon request

11. Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. K. Kremer, Prof. Dr. F. Schmid
Lecturers: All lecturers in theoretical condensed matter physics

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

Module Topical Courses: „Modern Comp. Techniques in Condensed/Soft Matter Physics“

<table>
<thead>
<tr>
<th>ID number</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.128.745</td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

1. Courses/Teaching methods

Lectures with exercises
„Computer simulations in statistical physics“ (WP)

Lectures (WP)

Exercises (WP)

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 h</td>
<td>6 LP</td>
<td></td>
</tr>
<tr>
<td>3 SWS/31.5 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 SWS/10.5 h</td>
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</tr>
</tbody>
</table>

2. Group sizes
Lecture: unlimited
Exercise: 20

3. Qualification and program goals/Competences
Students attending the course will learn the use of advanced tools and techniques for efficiently performing computer simulations in the field of condensed and soft matter physics, possibly including molecular biophysics. These techniques will enable them to study phenomena like phase transitions in a variety of systems (liquids, solids, polymer melts etc.), conformational changes, chemical reactions, non-equilibrium or driven phenomena etc.

4. Course content
The topics of the course will be selected according to the docent and can include free energy calculations, enhanced sampling techniques, simulation of rare events, critical phenomena, non-equilibrium dynamics, coarse-graining, density functional theory, force-field optimization, polarizable force fields, long range interactions, etc.

5. Applicable to the following programs
MSc. Physics, Master “Computational Sciences” with focus on physics

6. Recommended prerequisites
Module Topical Courses: „Modern Comp. Techniques in Condensed/Soft Matter Physics“

Theory 1-4, if possible (not strictly necessary) Theory 7 (Advanced Statistical Mechanics), Computer Simulations in Statistical Physics

7. Entry requirements

8. Mode and duration of examinations
   8.1. Active participation
   Successful completion of the exercises
   8.2. Course achievements

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

9. Weighting of the achievement in the overall grade
   6/120

10. Frequency of the module offering
    At least once per year

11. Persons responsible for this module and full-time lecturers
    Responsible: Prof. Dr. F. Schmid
    Lecturers: All lecturers in condensed matter theory

12. Auxiliary Information
    Course language: German or English on request
    Literature: To be announced in class

Module Topical Courses: „Computer Simulations in Statistical Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.801</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
   Contact time Self-study Credit Points
   Lectures with exercises
   „Computer Simulations in Statistical Physics“ (WP)
   Lectures (WP) 3 SWS/31.5 h 6 LP
   Exercises (WP) 1 SWS/10.5 h

2. Group sizes
   Lecture: unlimited
   Excercise: 20

3. Qualification and program goals/Competences
   Students will learn to describe complex physical problems in terms of simple models, to translate these into algorithms, and to implement the algorithms correctly and in an efficient way on modern computer architectures. They will learn to appreciate the importance of computer simulations in their interaction with theory and experiment.

4. Course content
   Molecular dynamics simulations, symplectic integrators, Markov chain Monte Carlos, random number generators, analysis of time series, finite size effects and simulations in different thermodynamic ensembles.

5. Applicable to the following programs
   MSc. Physics

6. Recommended prerequisites
<table>
<thead>
<tr>
<th>Module Topical Courses: „Computer Simulations in Statistical Physics“</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7. Entry requirements</strong></td>
</tr>
<tr>
<td><strong>8. Mode and duration of examinations</strong></td>
</tr>
<tr>
<td>8.1. Active participation</td>
</tr>
<tr>
<td>Successful completion of the exercises</td>
</tr>
<tr>
<td>8.2. Course achievements</td>
</tr>
<tr>
<td>8.3. Module examination</td>
</tr>
<tr>
<td>Common oral examination (30 – 45 Min.) covering two topical courses</td>
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<td><strong>9. Weighting of the achievement in the overall grade</strong></td>
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<tr>
<td>6/120</td>
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<tr>
<td><strong>10. Frequency of the module offering</strong></td>
</tr>
<tr>
<td>Every winter semester</td>
</tr>
<tr>
<td><strong>11. Persons responsible for this module and full-time lecturers</strong></td>
</tr>
<tr>
<td>Responsible: Prof. Dr. F. Schmid</td>
</tr>
<tr>
<td>Lecturers: Lecturers in theoretical condensed matter physics</td>
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<td><strong>12. Auxiliary Information</strong></td>
</tr>
<tr>
<td>Course language: German or English on request</td>
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<td>Literature:</td>
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<td>ID number 08.128.800</td>
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1. **Courses/Teaching methods**

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures with exercises „Theory of Soft Matter II“ (WP)</td>
<td>138 h</td>
<td>6 LP</td>
</tr>
<tr>
<td>Lectures (WP)</td>
<td>3 SWS/31.5 h</td>
<td></td>
</tr>
<tr>
<td>Excercises (WP)</td>
<td>1 SWS/10.5 h</td>
<td></td>
</tr>
</tbody>
</table>

2. **Group sizes**

- Lecture: unlimited
- Exercise: 20

3. **Qualification and program goals/Competences**

The students get acquainted with the statistical description of systems with large fluctuations, given the example of different soft matter systems. Special focus lies on general principles which can be applied for different material classes.

4. **Course content**

Topics are selected depending on the preferences of the lecturers. Possible topics are: DLVO theory, hydrodynamic interactions in colloids and polymers, micro swimmers and active particles, Zimm model, reptation model, networks and rubber elasticity, structure of polyelectrolytes, viscoelasticity, materials science aspects of soft matter systems, statistical physics of interfaces, wetting, capillary waves.

5. **Applicable to the following programs**

MSc. Physics

6. **Recommended prerequisites**

7. **Entry requirements**

8. **Mode and duration of examinations**

8.1. Active participation

成功的完成课程中的练习

8.2. Course achievements

8.3. Module examination

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

9. **Weighting of the achievement in the overall grade**

6/120

10. **Frequency of the module offering**

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

   Responsible: Prof. Dr. Kurt Kremer, Prof. Dr. F. Schmid
   Lecturers: All lecturers in theoretical condensed matter physics

12. **Auxiliary Informations**

   Course language: German or English on request

   Literature:
   - de Gennes, Scaling Concepts in Polymer Physics
   - Doi/Edwards, The Theory of Polymer Dynamics
   - Grosberg/Khokhlov, Statistical Mechanics of Macromolecules
   - Chaikin/Lubensky, Principles of Condensed Matter Physics
   - Russel/Saville/Schowalter, Colloidal Dispersions.
   - Dhont: An Introduction to Dynamics of Colloids
### Module Topical Courses: „Quantum Optics (Q-Ex-1)“

<table>
<thead>
<tr>
<th>ID number 08.128.729</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
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<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>1, Semester</td>
<td>6 LP</td>
<td></td>
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</tbody>
</table>

1. **Courses/Teaching methods**
   - **Lectures with exercises**
     - Quantum Optics (WP), frequently joint theoretical-experimental course
   - **Lectures (WP)**
     - 3 SWS/31.5 h
   - **Exercises (WP)**
     - 1 SWS/10.5 h

2. **Group sizes**
   - Lecture: unlimited
   - Exercise: 20

3. **Qualification and program goals/Competences**
   The students shall be introduced to the principles of the quantized description of radiation fields. Theoretical methods shall be discussed along with selected experiments which demonstrate effects of quantized radiation fields.

4. **Course content**
   Basic entry course to experimental quantum optics. Interdisciplinary experiment-theory course, frequently lectured jointly by experimentalists and theorists.
   **Contents:**
   - Quantization of electromagnetic fields, quantum states of radiation fields
   - Correlations in the radiation field and in photon statistics
   - Quantized interaction of atoms with light, Jaynes-Cummings Hamiltonian
   - "dressed states"
   **Further possible topics:**
   - Photon detectors
   - Single photon sources and entangled photons
   - Bell equations, quantum mechanical correlations of entangled photon pairs
   - Cavity quantum electrodynamics

5. **Applicable to the following programs**
   - MSc. Physics

6. **Recommended prerequisites**
   - Experimental Physics 5a “Atomic and Quantum Physics”, Theoretical Physics 3 “Quantum Mechanics”

7. **Entry requirements**

8. **Mode and duration of examinations**
   - **8.1. Active participation**
     - Successful completion of the exercises
   - **8.2. Course achievements**
   - **8.3. Module examination**
     - Common oral examination (30 – 45 Min.) covering two topical courses

9. **Weighting of the achievement in the overall grade**
   - 6/120

10. **Frequency of the module offering**
Module Topical Courses: „Quantum Optics (Q-Ex-1)“

- Annually in winter term

11. Persons responsible for this module and full-time lecturers
   Responsible: Prof. Dr. J. Walz
   Lecturers: All lecturers in experimental physics

12. Auxiliary Information
   - Course language: German or English
   - Literature: Textbooks on quantum optics and light-atom interaction,
     - Introductory quantum optics, Gerry & Knight
     - The quantum theory of light, Loudon
     - Quantum optics, Scully & Zubairy
     - Quantum optics, Walls & Milburn
     - Atom photon interactions, Cohen-Tannoudji, Dupont-Roc & Grynberg.

Module Topical Courses: „Photonics (Q-Ex-2)“

<table>
<thead>
<tr>
<th>ID number 08.128.803</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
   - Lectures with exercises „Photonics“ (WP) 138 h 6 LP
     - Lectures (WP) 3 SWS/31.5 h
     - Exercises (WP) 1 SWS/10.5 h

2. Group sizes
   - Lecture: unlimited
   - Exercise: 20

3. Qualification and program goals/Competences
   The students shall be introduced to the advanced description of light propagation and the interaction with matter. A deep understanding of laser spectroscopy – based on incoherent and coherent light-matter interaction and highly stable lasers shall be acquired; in particular the difference between coherent and incoherent processes will be detailed. The students should learn to understand the working principle of lasers and fundamentals of non-linear optics.

4. Course content
   - Fundamentals of experimental quantum physics. Possible topics:
     - Gaussian optics and resonators
     - connection between classical, semi-classical and quantum mechanical description of light-matter interaction
     - coherent light and lasers
     - laser modulators, optical fibers
     - short pulses and frequency comb techniques
     - incoherent spectroscopy techniques (absorption, fluorescence, Doppler-free, frequency modulation)
     - comparison with coherent techniques (Rabi, Ramsey, Spin-Echo)
     - non-linear media, sum- and difference frequency generation, \( \chi^{(2)} \) vs. \( \chi^{(3)} \) processes,
     - laser cooling

5. Applicable to the following programs
   - MSc. Physics

6. Recommended prerequisites
   - Experimental physics 3 “Waves and Quantum Mechanics”, 5a “Atomic and Quantum Physics”, Theoretical Physics 3 “Quantum Mechanics”
## Module Topical Courses: „Photonics (Q-Ex-2)“

### 7. Entry requirements

### 8. Mode and duration of examinations

**8.1. Active participation**
- successful completion of the exercises

**8.2. Course achievements**

**8.3. Module examination**
- Common oral examination (30 – 45 Min.) covering two topical courses

### 9. Weighting of the achievement in the overall grade

6/120

### 10. Frequency of the module offering

Annually in summer term

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

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

**Lecturers:** All lecturers in experimental physics

### 12. Auxiliary Information

- **Course language:** German or English
- **Literature:** Specialized textbooks in photonics, e.g.
  - Laser Spectroscopy, W. Demtröder
  - Optics, Light and Lasers, D. Meschede
  - Lasers, A.E. Siegman,
  - Fundamentals of Photonics, B. E. A. Saleh and M.C. Teich
  - publications close to current research.

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## Module Topical Courses: „Quantum Information (Q-Ex-3)“

<table>
<thead>
<tr>
<th>ID number 08.128.804</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

### 1. Courses/Teaching methods

- **Lectures with exercises**
  - "Quantum Information“ (WP) frequently joint theoretical-experimental course

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
<th>3 SWS/31.5 h</th>
<th>6 LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises (WP)</td>
<td>1 SWS/10.5 h</td>
<td></td>
</tr>
</tbody>
</table>

### 2. Group sizes

- Lecture: unlimited
- Exercise: 20

### 3. Qualification and program goals/Competences

- Based on their knowledge of atomic and quantum physics as well as quantum mechanics, the students will study and derive the basic theoretical concepts of quantum information processing and quantum computing. On the experimental side, concepts, experimental realizations, platforms and applications of these concepts will be introduced involving the necessary aspects of quantum optics.

### 4. Course content
Module Topical Courses: "Quantum Information (Q-Ex-3)"

Advanced course in the field of quantum optics, atomic physics and its application to quantum information. "Stand-alone" course, applies concepts from Quantum Optics and many body physics. Interdisciplinary course, frequently lectured jointly by experimentalists and theorists.

Contents:
- storage and processing to quantum information in different systems
- lead to quantum communication and computing
- entangled states, quantum jumps, quantum Zeno effect
- decoherence, macroscopical quantum superposition ("Schrödinger cat states")

Further possible topics:
- quantum gates and algorithms
- quantum cryptography, quantum teleportation, quantum repeaters
- error correction, error prone quantum processing
- quantum simulation
- Systems: ion trap, in particular Paul trap based quantum computers, cavity QED, linear optical quantum computers, neutral atoms in optical lattices, solid state and superconducting quantum processors.

5. Applicable to the following programs
MSc. Physics

6. Recommended prerequisites
Experimental Physics 5a "Atomic - and Quantum Physics", Theoretical Physics 3 "Quantum Mechanics"

7. Entry requirements

8. Mode and duration of examinations
8.1. Active participation
successful completion of the exercises
8.2. Course achievements

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

9. Weighting of the achievement in the overall grade
6/120

10. Frequency of the module offering
Annually in summer term

11. Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. F. Schmidt-Kaler
Lecturers: Selected lecturers in experimental physics, WA Quantum

12. Auxiliary Information
Course language:
- German or English

Literature: Text books on quantum optics and quantum information processing, i.e.
- Introductory quantum optics, Gerry & Knight
- Quantum Computation and Quantum Information, Nielsen & Chuang
- Introduction to Quantum Computation and Quantum Information, Lo, Popescu & Spiller
- The Physics of Quantum Information, Bouwmeester, Ekert & Zeilinger
- Exploring the Quantum - Atoms, Cavities and Photons, Haroche & Raimond

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

| ID number 08.128.805 | Workload | Duration of Course | Designated term | Credit Points |
### Module Topical Courses: „Precision fundamental physics (Q-Ex-4)“

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td></td>
<td>6 LP</td>
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</table>

#### 1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with exercises</th>
<th>„Precision Experiments at Lowest Energies“ (WP)</th>
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<tbody>
<tr>
<td>Contact time</td>
<td>Self-study</td>
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<tr>
<td>138 h</td>
<td>6 LP</td>
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</table>

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
<th>3 SWS/31.5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excercises (WP)</td>
<td>1 SWS/10.5 h</td>
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</tbody>
</table>

#### 2. Group sizes

- Lecture: unlimited
- Exercise: 20

#### 3. Qualification and program goals/Competences

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

#### 4. Course content

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

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

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

#### 5. Applicable to the following programs

- MSc. Physics

#### 6. Recommended prerequisites

- Experimental Physics 5a "Atomic and Quantum Physics", Theoretical Physics 3 "Quantum Mechanics"

#### 7. Entry requirements

#### 8. Mode and duration of examinations

- **8.1. Active participation**
  - successful completion of the exercises

- **8.2. Course achievements**

- **8.3. Module examination**
  - Common oral examination (30 – 45 Min.) covering two topical courses

#### 9. Weighting of the achievement in the overall grade

- 6/120

#### 10. Frequency of the module offering

- Annually in winter term

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

- Responsible: Prof. Dr. J. Walz
- Lecturers: All lecturers in experimental physics

#### 12. Auxiliary Informations
<table>
<thead>
<tr>
<th>Course language:</th>
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<tbody>
<tr>
<td>• German or English</td>
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</table>

<table>
<thead>
<tr>
<th>Literature:</th>
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<tbody>
<tr>
<td>• Textbooks in atomics physics</td>
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<tr>
<td>• proceedings of summer-schools</td>
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<tr>
<td>• publications close to current research.</td>
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Module Topical Courses: „Statistics, Data Analysis and Simulation”

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<th>ID number 08.128.730</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1st Semester</td>
<td>6 LP</td>
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</tbody>
</table>

1. Courses/Teaching methods

- Lectures with exercises
  - „Statistics, data analysis and simulation“ (WP) 
    - Contact time: 138 h
    - Contact time: 6 LP

- Lectures (WP)
  - 3 SWS/31.5 h

- Exercises (WP)
  - 1 SWS/10.5 h

2. Group sizes

- Lecture: unlimited
- Exercise: 20

3. Qualification and program goals/Competences

The course provides an overview of the statistical methods to analyze data and offers an introduction to Monte Carlo techniques. While the methods are often introduced with the help of examples taken from the areas of particle, hadronic and nuclear physics, we recommend the lectures also to students specializing in other fields. The goal of the course is to provide a solid basis that helps to successfully complete a master’s thesis in a related area of physics.

4. Course content

The following areas shall be covered:
- Probability distributions and the statistical description of data;
- error propagations and the estimation of parameters;
- significance levels and decisions on hypotheses;
- Monte Carlo methods, as well as
- Statistical analysis methods.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites


7. Entry requirements


8. Mode and duration of examinations

- 8.1. Active participation
  - successful completion of the exercises

- 8.2. Course achievements

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

9. Weighting of the achievement in the overall grade

6/120

10. Frequency of the module offering

  - Every summer semester

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

  - Responsible: Prof. Dr. L. Köpke
  - Lecturers: All lecturers in experimental nuclear and particle physics

12. Auxiliary Informations
### Module Topical Courses: „Statistics, Data Analysis and Simulation”

**Course language:** German or English on request  
**Literature:**  
- R.J. Barlow, Statistics  
- Glen Cowan, Statistical data analysis  
- Olaf Behnke, Data analysis in high energy physics

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### Module Topical Courses: „Particle Detectors“

<table>
<thead>
<tr>
<th>ID number 08.128.731</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Courses/Teaching methods</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures with exercises „Particle Detectors“ (WP)</td>
<td>138 h</td>
<td>6 LP</td>
<td></td>
</tr>
<tr>
<td>Lectures (WP)</td>
<td>3 SWS/31.5 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercises (WP)</td>
<td>1 SWS/10.5 h</td>
<td></td>
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</tbody>
</table>

**Group sizes**
- Lecture: unlimited  
- Exercise: 20

**Qualification and program goals/Competences**
The course provides an overview of the detection, read-out and analysis techniques used in particle, hadron, nuclear, and astroparticle physics. The goal is to provide a solid basis for the successful completion of a master’s thesis. Cross disciplinary aspects (solid state physics, electronics, mathematics, and computer science) play important roles. Therefore the course is also suitable to students that focus on other areas of physics.

**Course content**
The following subjects shall be covered:
- Particle sources and accelerators;
- Detection methods for charged and neutral radiation;
- Data acquisition;
- Particle detectors to measure time, energy, momentum and particle type;
- Applications in complex detector systems.

**Applicable to the following programs**
- MSc. Physics

**Recommended prerequisites**

**Entry requirements**

**Mode and duration of examinations**

8.1. Active participation

Successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

**Weighting of the achievement in the overall grade**

6/120

**Frequency of the module offering**

Every winter semester
### Module Topical Courses: „Particle Detectors“

11. Persons responsible for this module and full-time lecturers
   - Responsible: Prof. Dr. L. Köpke
   - Lecturers: All lecturers in experimental nuclear and particle physics

12. Auxiliary Informations
   - Course language:
     1. German or English on request
   - Literature:
     2. K. Kleinknecht, Detectors for particle radiation
     3. C. Grupen, B. Shwartz, Particle Detectors

### Module Topical Courses: „Cosmology and General Relativity“

<table>
<thead>
<tr>
<th>ID number 08.128.732</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

1. Courses/Teaching methods
   - Contact time
   - Self-study
   - Credit Points
   - Lectures with exercises „Cosmology and General Relativity“ (WP)
   - Lectures (WP): 3 SWS/31,5 h
   - Exercises (WP): 1 SWS/10,5 h
   - 138 h 6 LP

2. Group sizes
   - Lecture: unlimited
   - Exercise: 20

3. Qualification and program goals/Competences
   - The lectures’ program goal is to provide a basic understanding of the theory of General Relativity as well as of the current concepts and phenomena of cosmology.

4. Course content
   - General coordinate transformations, differential geometry, Einstein equation, Schwarzschild metric, black holes, Friedmann-Robertson-Walker cosmology, big-bang nucleosynthesis, cosmic microwave background, structure development in the early universe, dark matter and dark energy.

5. Applicable to the following programs
   - MSc. Physics

6. Recommended prerequisites
   - Knowledge corresponding to Theoretical Physics 5 (Classical Field Theory)

7. Entry requirements

8. Mode and duration of examinations
   - 8.1. Active participation
     - successful completion of the exercises
   - 8.2. Course achievements
   - 8.3. Module examination
     - Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade
   - 6/120

10. Frequency of the module offering

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Module Topical Courses: “Cosmology and General Relativity“

11. Persons responsible for this module and full-time lecturers
   Responsible: Prof. Dr. M. Neubert
   Lecturers: Häusling, Neubert, Papadopoulos, Reuter, Spiesberger, Weinzierl

12. Auxiliary Informations
   Course language:
   4. German or English on request
   Literature:
   5. Caroll, Wald, Kolb & Turner, Dodelson

Module Topical Courses: “Symmetries in Physics“

<table>
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<tr>
<th>ID number 08.128.733</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

Courses/Teaching methods
Lectures with exercises
   “Symmetries in Physics“ (WP)
Lectures (WP) 3 SWS/31.5 h
Excercises (WP) 1 SWS/10.5 h

Group sizes
Lecture: unlimited
Exercise: 20

Qualification and program goals/Competences
The lectures’ program goal is to provide a basic understanding of group theory and its’ applications in physics.

Course content
Group theory, representations, unitary symmetries, Lie groups, applications and exercises in particle and nuclear physics.

Applicable to the following programs
MSc. Physics

Recommended prerequisites

Entry requirements

Mode and duration of examinations
8.1. Active participation
   successful completion of the exercises
8.2. Course achievements
8.3. Module examination
   Common oral examination (30 – 45 Min.) covering two topical courses

Weighting of the achievement in the overall grade
6/120

Persons responsible for this module and full-time lecturers
### Module Topical Courses: „Symmetries in Physics“

**Responsible:** Prof. Dr. M. Neubert  
**Lecturers:** Neubert, Scherer, Spiesberger, Weinzierl  

**Auxiliary Informations**
- **Course language:** German or English on request
- **Literature:** Georgi, Tung

### Module Topical Courses: „Modern Methods in Theoretical High Energy, Particle and Nuclear Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.733, 08.128.741-744</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Courses/Teaching methods</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
</table>
| **Lectures with exercises**
**„Modern Methods in Theoretical High Energy, Particle and Nuclear Physics“ (WP)** | 138 h | 6 LP |
| **Lectures (WP)** | 3 SWS/31.5 h | |
| **Exercises (WP)** | 1 SWS/10.5 h | |

<table>
<thead>
<tr>
<th>Group sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture: unlimited</td>
</tr>
<tr>
<td>Exercise: 20</td>
</tr>
</tbody>
</table>

**Qualification and program goals/ Competences**

The lectures' program goal is to provide a basic understanding of a topic related to current research in the field of high energy, particle and nuclear physics. An additional goal is to teach the methods which are required for the master's thesis.

**Course content**

Concerning to the lecturer the focus is put on a current scientifically topic from the following research areas: electroweak and strong interactions, lattice gauge theory, effective field theories, mathematical aspects of perturbation theory, functional integration in quantum mechanics and quantum field theory, concepts of model building beyond the standard model (e.g. supersymmetry, string theory) and others. Lectures of this module are offered by different lecturers and topics can change every semester. In this case a student can subscribe to this module more than once and the module will not be counted as identical.

**Applicable to the following programs**

MSc. Physics

**Recommended prerequisites**

Theoretical Physics 5 (Classical Field Theory), Theoretical Physics 6 (Quantum Field Theory)

**Entry requirements**

**Mode and duration of examinations**

8.1. Active participation  
Successful completion of the exercises

8.2. Course achievements

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

**Weighting of the achievement in the overall grade**  
6/120

**Frequency of the module offering**
Module Topical Courses: „Modern Methods in Theoretical High Energy, Particle and Nuclear Physics“

Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. M. Neubert, Prof. Dr. H. Wittig
Lecturers:

Auxiliary Information
Course language:
8. German or English on request
Literature:
9. various textbooks, publications close to science

Module Topical Courses: „Accelerator Physics“

<table>
<thead>
<tr>
<th>ID number</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.128.735</td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</tbody>
</table>

Courses/Teaching methods

- Lectures with excercises
  „Accelerator Physics“ (WP)

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
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<tbody>
<tr>
<td>138 h</td>
<td></td>
<td>6 LP</td>
</tr>
</tbody>
</table>

Lectures (WP) 3 SWS/31.5 h
Excercises (WP) 1 SWS/10.5 h

Group sizes

Lecture: unlimited
Excercise: 20

Qualification and program goals/Competences

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

Course content

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

Applicable to the following programs

MSc. Physics

Recommended prerequisites

Entry requirements

Mode and duration of examinations

8.1. Active participation
successful completion of the exercises

8.2. Course achievements

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

Weighting of the achievement in the overall grade
Module Topical Courses: „Accelerator Physics“

6/120

- Frequency of the module offering
  Every winter semester

- Persons responsible for this module and full-time lecturers
  Responsible: Prof. Dr. K. Aulenbacher
  Lecturers: Prof. Dr. K. Aulenbacher

- Auxiliary Informations
  Course language:
  10. German or English on request
  Literature:

Module Topical Courses: „Astroparticle Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.737</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
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<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
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</table>

1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with exercises „Astroparticle Physics“ (WP)</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures (WP)</td>
<td>138 h</td>
<td></td>
<td>6 LP</td>
</tr>
<tr>
<td>Exercises (WP)</td>
<td>3 SWS/31,5 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 SWS/10,5 h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Group sizes

- Lecture: unlimited
- Exercise: 20

3. Qualification and program goals/Competences

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

4. Course content

The main themes of the course relate to:

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

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

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

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

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation
Module Topical Courses: „Astroparticle Physics“

Successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

9. Weighting of the achievement in the overall grade

6/120

10. Frequency of the module offering

Every summer semester

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

Responsible: Prof. Dr. L. Köpke, Prof. Dr. U. Oberlack
Lecturers: Prof. S. Böser, Apl Prof. Dr. Egelhoff, Apl Prof. Dr. Kabuss, Prof. Dr. Köpke, Prof. U. Oberlack, Prof. M. Wurm.

12. Auxiliary Information

Course language: German or English on request

Literature:
- A. Liddle, An introduction to modern cosmology
- P. Schneider, Extragalaktische Astronomie und Kosmologie
- C. Grupen, Astroteilchenphysik
- D. Perkins, Particle Astrophysics

Module Topical Courses: „Particle Physics“

ID number 08.128.738  Workload Duration of Course Designated term Credit Points
180 h 1 Semester 1. Semester 6 LP

1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Lectures with exercises „Particle Physics“ (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 SWS/31.5 h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercises (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 SWS/10.5 h</td>
</tr>
</tbody>
</table>

2. Group sizes

Lecture: unlimited
Exercise: 20

3. Qualification and program goals/Competences

The course is intended to deepen the understanding of the fundamental building blocks of matter and their interactions. Basic principles will be covered by using topical research as an example. The course provides the required knowledge in order to successfully complete a master’s thesis in a related subject.

4. Course content

The following subjects shall be covered:
- Brief outline of experimental methods,
- Symmetries and the quark model,
- Lepton scattering at high energies,
- Particles and interaction in the Standard Model, as well as models for its unification and extension.

While covering the subjects, groundbreaking and actual experiments will be discussed. Depending on the docent’s interest, extension of the Standard Model or bound systems will be covered in more detail.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites
### Module Topical Courses: „Particle Physics“

<table>
<thead>
<tr>
<th>7. Entry requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>8. Mode and duration of examinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1. Active participation</td>
</tr>
<tr>
<td>successful completion of the exercises</td>
</tr>
<tr>
<td>8.2. Course achievements</td>
</tr>
<tr>
<td>8.3. Module examination</td>
</tr>
<tr>
<td>Common oral examination (30 – 45 Min.) covering two topical courses</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>9. Weighting of the achievement in the overall grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/120</td>
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<table>
<thead>
<tr>
<th>10. Frequency of the module offering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every semester</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>11. Persons responsible for this module and full-time lecturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsible: Prof. Dr. L. Köpke</td>
</tr>
<tr>
<td>Lecturers: All lecturers in experimental nuclear and particle physics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12. Auxiliary Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course language: English</td>
</tr>
<tr>
<td>Literature:</td>
</tr>
<tr>
<td>- <a href="#">C. Berger, Elementarteilchenphysik, Springer-Verlag, 2006.</a></td>
</tr>
<tr>
<td>- <a href="#">D. Griffiths, Introduction to Elementary Particles, Wiley-VCH Verlag, 2008.</a></td>
</tr>
<tr>
<td>- <a href="#">E. Lohrmann, Hochenergiephysik, Teubner-Verlag, 2005.</a></td>
</tr>
<tr>
<td>- <a href="#">D. H. Perkins, High Energy Physics</a></td>
</tr>
<tr>
<td>- <a href="#">B. Povh et al., Teilchen und Kerne</a></td>
</tr>
</tbody>
</table>

### Module Topical Courses: „Theoretical Particle Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.809</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>1. Semester</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1. Courses/Teaching methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures with exercises</td>
</tr>
<tr>
<td>„Theoretical Particle Physics“ (WP)</td>
</tr>
<tr>
<td>Contact time</td>
</tr>
<tr>
<td>Self-study</td>
</tr>
<tr>
<td>138 h</td>
</tr>
<tr>
<td>6 LP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1. Lectures (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 SWS/31.5 h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Exercises (WP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 SWS/10.5 h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Group sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture: unlimited</td>
</tr>
<tr>
<td>Exercise: 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Qualification and program goals/Competences</th>
</tr>
</thead>
<tbody>
<tr>
<td>The lecture course “Theoretical Particle Physics” builds upon and continues the lecture course “Relativistic Quantum Field Theory”. The lectures’ program goal is to provide a basic understanding of concepts and methods of quantum field theory which are required for a MA thesis in theoretical particle physics.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Course content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path integral formalism, quantum corrections, renormalization in QED, renormalization group; non-Abelian gauge theories, quantum chromodynamics (QCD), spontaneous symmetry breaking, Higgs mechanism, standard model of particle physics.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5. Applicable to the following programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSc. Physics</td>
</tr>
</tbody>
</table>
### Module Topical Courses: „Theoretical Particle Physics“

6. Recommended prerequisites
   - Relativistic Quantum Field Theory

7. Entry requirements

8. Mode and duration of examinations
   - **8.1. Active participation**
     - successful completion of the exercises
   - **8.2. Course achievements**

8.3. Module examination
   - Common oral examination (30 – 45 Min.) covering both topical courses

9. Weighting of the achievement in the overall grade
   - 6/120

10. Frequency of the module offering
    - Usually every semester

11. Persons responsible for this module and full-time lecturers
    - Responsible: Prof. Dr. S. Weinzierl
    - Lecturers: All professors of theoretical high energy physics

12. Auxiliary Information
    - **Course language:**
      - German or English on request
    - **Literature:**
      - Peskin & Schroeder, Ryder, Schwartz, Zee

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### Module Topical Courses: „Introduction to Lattice Gauge Theory“

<table>
<thead>
<tr>
<th>ID number 08.128.746</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td></td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**
   - **Lectures with exercises**
     - „Introduction to Lattice Gauge Theory“ (WP)
   - **Lectures (WP)**
     - 3 SWS/31.5 h
   - **Exercises (WP)**
     - 1 SWS/10.5 h

2. **Group sizes**
   - Lecture: unlimited
   - Exercise: 20

3. **Qualification and program goals/Competences**
   - The lectures’ program goal is to provide a basic understanding of the methods of lattice gauge theory and its applications to problems in particle and nuclear physics. A particular goal is to teach the methods which are required for pursuing a master’s thesis in this field.

4. **Course content**
Module Topical Courses: „Introduction to Lattice Gauge Theory“

- Discretization of PDEs by finite differences; path integral in quantum mechanics; Euclidean correlation functions in QFT; transfer matrix; scalar field theories on the lattice and spin models; Ising model at high and low temperature; $Z_2$ lattice gauge theory, Elitzur's theorem and Wegner loop; QED and QCD in the continuum; Wilson loop; lattice gauge theory with Wilson action; Haar measure; fermions on the lattice; static potential and strong-coupling expansion; renormalization group and continuum limit; lattice perturbation theory; Monte Carlo simulations and determination of hadronic properties.

5. Applicable to the following programs
   MSc. Physics

6. Recommended prerequisites
   Theoretical Physics 6 (Quantum Field Theory)

7. Entry requirements

8. Mode and duration of examinations
   8.1. Active participation
   8.2. Course achievements
   8.3. Module examination
   Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade
   6/120

10. Frequency of the module offering
    Irregular

11. Persons responsible for this module and full-time lecturers
    Responsible: Prof. Dr. H. Wittig
    Lecturers: Prof. Dr. H. Wittig, Prof. Dr. H. Meyer, PD Dr. G. von Hippel

12. Auxiliary Information
    Course language: English

    Literature:

Module Topical Courses: „Introduction to String Theory“

<table>
<thead>
<tr>
<th>ID number 08.128.760</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
   Lectures with excercises „Introduction to String Theory“ (WP)
   Lectures (WP) 3 SWS/31.5 h
   Exercices (WP) 1 SWS/10.5 h

2. Group sizes
## Module Topical Courses: „Introduction to String Theory“

<table>
<thead>
<tr>
<th>Lecture: unlimited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercice: 20</td>
</tr>
</tbody>
</table>

### 3. Qualification and program goals / Competences

The lectures' program goal is to provide a basic understanding of classical and quantised bosonic and fermionic string theories. An additional goal is to teach methods which are required for the master's thesis.

### 4. Course content

Classical bosonic string, quantisation (lightcone, covariant, path integral, BRST formalism), D-branes, superstrings, introduction to conformal field theory, string amplitudes.

### 5. Applicable to the following programs

MSc. Physics

### 6. Recommended prerequisites

Recommended, but not required: Theoretical Physics 6 (Quantum Field Theory), Cosmology and General Relativity

### 7. Entry requirements

### 8. Mode and duration of examinations

#### 8.1. Active participation

Successful completion of the exercises

#### 8.2. Course achievements

#### 8.3. Module examination

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

### 9. Weighting of the achievement in the overall grade

6/120

### 10. Frequency of the module offering

Irregular

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

Responsible: Prof. Dr. G. Honecker
Lecturers: All professors of theoretical high energy physics

### 12. Auxiliary Information

Course language: English

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

- Blumenhagen, Lüst, Theisen: Basic Concepts of String Theory, Springer 2012;

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## Module Topical Courses: „Effective Field Theories“

| ID number 08.128.766 | Workload | Duration of Course | Designated term | Credit Points |
|-----------------------|----------|--------------------|-----------------|--------------|--------------|

48
## Module Topical Courses: „Effective Field Theories“

<table>
<thead>
<tr>
<th>180 h</th>
<th>1 Semester</th>
<th>2. Semester</th>
<th>6 LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Courses/Teaching methods</td>
<td></td>
<td>Contact time</td>
<td>Self-study</td>
</tr>
<tr>
<td>Lectures with excercises „Effective Field Theories“ (WP)</td>
<td></td>
<td>138 h</td>
<td>6 LP</td>
</tr>
<tr>
<td>Lectures (WP)</td>
<td></td>
<td>3 SWS/31.5 h</td>
<td></td>
</tr>
<tr>
<td>Excercises (WP)</td>
<td></td>
<td>1 SWS/10.5 h</td>
<td></td>
</tr>
</tbody>
</table>

2. Group sizes
   - Lecture: unlimited
   - Excercise: 20

3. Qualification and program goals/Competences
   The lectures introduce the basic ideas of the effective field theory approach like relevant and irrelevant operators, renormalization group, decoupling of heavy particle. The lectures also provide a deeper understanding of its most important applications in modern research fields.

4. Course content
   The method of effective field theory provides a systematic approach to multi-scale problems. An effective field theory uses the appropriate degrees of freedom to describe the phenomena at a given energy scale, while all degrees of freedom only relevant at much higher scales are eliminated from the theory. These concepts lead to a large variety of phenomenological applications in modern particle physics. Especially in the theory of strong interactions with its different behaviour at the various energy scales the important examples of the electroweak Lagrangian, heavy-quark-effective theory, and soft-collinear-effective theories allow for most suitable descriptions of the respective theoretical systems.

5. Applicable to the following programs
   - MSc. Physics

6. Recommended prerequisites
   - Theoretical Physics 6 (Quantum Field Theory)

7. Entry requirements

8. Mode and duration of examinations
   - 8.1. Active participation
   - successful completion of the exercises
   - 8.2. Course achievements
   - 8.3. Module examination
     - Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade
   - 6/120

10. Frequency of the module offering
    - Irregular

11. Persons responsible for this module and full-time lecturers
    - Responsible: Prof. Dr. M. Neubert
    - Lecturers: All professors of theoretical high energy and hadron physics

12. Auxiliary Information
Module Topical Courses: „Effective Field Theories“

Course language: English

Literature:
- Lecture notes “Effective Field Theory” by A. Pich
- Lecture notes "Effective Field Theories" by A. Manohar
- Lecture notes "Effective Field Theories and Heavy Quark Physics" by M. Neubert

Module Topical Courses: „Theoretical Astroparticle Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.762</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

**Lectures with exercises**

„Theoretical Astroparticle Physics“ (WP)

- Contact time: 138 h
- Self-study: 6 LP

**Lectures (WP)**

- 3 SWS/31.5 h

**Excercises (WP)**

- 1 SWS/10.5 h

2. Group sizes

Lecture: unlimited
Excercise: 20

3. Qualification and program goals/Competences

This lecture aims to give, from a theorists point of view, a broad but thorough overview of state of the art astroparticle physics. Its goal is to prepare students to understand the current scientific literature on cosmology, dark matter, neutrinos and related topics and to prepare them for their own research projects (Master / PhD) in experimental or theoretical astroparticle physics.

4. Course content

The big bang theory (Friedmann equation, expansion of the Universe); big bang nucleosynthesis; cosmic microwave background; formation of structure in the Universe; dark matter (production in the early Universe by thermal freeze-out, searches in terrestrial and astrophysical experiments); the cosmic matter–antimatter asymmetry; high energy cosmic rays; neutrinos (mechanisms to explain the smallness of neutrino masses; theory and phenomenology of neutrino oscillations; impact of neutrinos on cosmology; supernova neutrinos); axions

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Theoretical Physics 6 (Quantum Field Theory)

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation

successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

9. Weighting of the achievement in the overall grade

6/120

10. Frequency of the module offering
Module Topical Courses: „Theoretical Astroparticle Physics“

<table>
<thead>
<tr>
<th>Irregular</th>
</tr>
</thead>
</table>

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

Responsible: Prof. Dr. J. Kopp
Lecturers: All professors of theoretical high energy physics

12. Auxiliary Information

Course language: English
Literature:
- various textbooks, publications close to science

Module Topical Courses: „Amplitudes and Precision Physics at the LHC“

<table>
<thead>
<tr>
<th>ID number 08.128.764</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
<td></td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

- Lectures with exercises
  „Amplitudes and Precision Physics at the LHC“ (WP)
  - 138 h
  - 6 LP

- Lectures (WP) 3 SWS/31.5 h
- Exercises (WP) 1 SWS/10.5 h

2. Group sizes

- Lecture: unlimited
- Exercise: 20

3. Qualification and program goals/Competences

The goal of this lecture is to introduce students to recently developed methods for calculating scattering amplitudes within quantum field theory. A particular emphasis is put on the efficiency of the methods to be used. These new methods allow to predict cross sections for the experiments at the LHC, which are difficult to compute with traditional methods.

4. Course content

- Spin- and helicity methods, colour decomposition, off-shell recursion relations, on-shell recursion relations, scattering equations;
- loop integrals, differential equations for loop integrals, classes of functions (for example multiple polylogarithms).

5. Applicable to the following programs

- MSc. Physics

6. Recommended prerequisites

- Theoretical Physics 6 (Quantum Field Theory)

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation

Successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

9. Weighting of the achievement in the overall grade
<table>
<thead>
<tr>
<th>Module Topical Courses: „Amplitudes and Precision Physics at the LHC“</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/120</td>
</tr>
<tr>
<td>10. Frequency of the module offering</td>
</tr>
<tr>
<td>Irregular</td>
</tr>
<tr>
<td>11. Persons responsible for this module and full-time lecturers</td>
</tr>
<tr>
<td>Responsible: Prof. Dr. J. Henn, Prof. Dr. S. Weinzierl</td>
</tr>
<tr>
<td>Lecturers: All professors of theoretical high energy physics</td>
</tr>
<tr>
<td>12. Auxiliary Information</td>
</tr>
<tr>
<td>Course language: English</td>
</tr>
<tr>
<td>Literature:</td>
</tr>
<tr>
<td>- J. Henn, J. Plefka, „Scattering Amplitudes in Gauge Theories“, Springer, 2014;</td>
</tr>
</tbody>
</table>
Module Topical Courses: „Functional Methods and Exact Renormalization Group“

<table>
<thead>
<tr>
<th>ID number 08.128.747</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

   Lectures with exercises „Functional Methods and Exact Renormalization Group“ (WP)

   Lectures (WP) 3 SWS/31.5 h
   Exercises (WP) 1 SWS/10.5 h

2. Group sizes

   Lecture: unlimited
   Exercise: 20

3. Qualification and program goals/Competences

   The goal of this lecture is to introduce students to path integrals, functional integral quantization of field theories and the functional renormalization group equation.

4. Course content

   (A) Path integrals in quantum mechanics:
   
   Relation to the canonical approach, discretization and operator ordering, topological aspects (multiply connected configuration spaces, etc.), evaluation of functional integrals (exactly soluble examples, semiclassical expansion, perturbation theory), instantons in quantum mechanics (double well, periodic potentials, n- and Theta-vacua).

   (B) Functional integral quantization of field theories:
   
   Functional Schroedinger picture, wave functionals, field-particle relationship, symmetry and covariance properties, from transition amplitudes to (vacuum-) correlators and generating functionals, the Schwinger-Symanzik approach, functional integral representation via the Schroedinger picture and the Schwinger-Symanzik approach, the effective action (canonical and diagrammatic approaches, Legendre-Fenchel transform), computational techniques (semiclassical and perturbative expansion), perturbative Yang-Mills theory, nonperturbative Yang-Mills theory ("large" gauge transformations, homotopy classes- and groups, instantons and tunneling, nonperturbative vacuum structure).

   (C) The functional renormalization group equation (FRGE):
   
   Functional (i.e. "exact") vs. perturbative renormalization, critical phenomena, Wilsonian renormalization group in statistical mechanics and quantum field theory (theory space, block spin transformations, coupling constant flows), notions of nonperturbative renormalizability, continuum limits and phase transitions, construction and "solution" of quantum field theories by means of FRGE methods.

5. Applicable to the following programs

   MSc. Physics

6. Recommended prerequisites

   Theoretical Physics 6 (Quantum Field Theory)

7. Entry requirements

8. Mode and duration of examinations

   8.1. Active participation
   successful completion of the exercises

   8.2. Course achievements

   8.3. Module examination
   Common oral examination (30 – 45 Min.) covering two topical courses
<table>
<thead>
<tr>
<th>Module Topical Courses: „Functional Methods and Exact Renormalization Group“</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Weighting of the achievement in the overall grade</td>
</tr>
<tr>
<td>6/120</td>
</tr>
<tr>
<td>10. Frequency of the module offering</td>
</tr>
<tr>
<td>Irregular</td>
</tr>
<tr>
<td>11. Persons responsible for this module and full-time lecturers</td>
</tr>
<tr>
<td>Responsible: Prof. Dr. M. Reuter</td>
</tr>
<tr>
<td>Lecturers: All professors of theoretical high energy physics</td>
</tr>
<tr>
<td>12. Auxiliary Information</td>
</tr>
<tr>
<td>Course language: English</td>
</tr>
</tbody>
</table>
Module Advanced Course: „Advanced Particle Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.806</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods

<table>
<thead>
<tr>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures with exercises „Advanced Particle Physics“ (WP)</td>
<td>138 h</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lectures (WP)</th>
<th>3 SWS/31.5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises (WP)</td>
<td>1 SWS/10.5 h</td>
</tr>
</tbody>
</table>

2. Group sizes

Lecture: unlimited  
Exercise: 20

3. Qualification and program goals/Competences

This course covers special aspects of the fundamental building blocks of matter and their interactions in detail. The newest experimental methods and results will be presented for topical research areas in particle physics. The course provides the students with advanced knowledge that will help in completing an experimental master’s thesis in a related research area.

4. Course content

The content of the course is variable and will typically include one of the following subjects:
- Lepton scattering at high energies,
- Strong interaction,
- Electro-weak interaction, as well as
- Models for the unification and extension of the Standard Model.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Knowledge on the level of the module Experimental Physics 5b “Nuclear and Particle Physics” is strongly recommended. Helpful, however not essential, is the successful completion of the Special Subject Course “Elementary Particle Physics”.

7. Entry requirements

8. Mode and duration of examinations

8.1. Active participation  
successful completion of the exercises

8.2. Course achievements

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

9. Weighting of the achievement in the overall grade  
6/120

10. Frequency of the module offering

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

Responsible: Prof. Dr. L. Köpke  
Lecturers: All lecturers in experimental particle physics

12. Auxiliary Information
Module Advanced Course: „Advanced Particle Physics“

Course language: German or English on request

Literature:
- C. Berger, Elementarteilchenphysik
- D. Griffiths, Introduction to Elementary Particles

Recommendations for specialized books and recent publication on current topics will be provided.

Module Advanced Course: „Advanced Chapters on Subatomic Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.807</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

Courses/Teaching methods

Lectures with exercises

„Advanced lecture on subatomic physics“ (WP)

Lectures (WP)

3 SWS/31.5 h

Exercises (WP)

1 SWS/10.5 h

Group sizes

Lecture: unlimited

Exercise: 20

Qualification and program goals/Competences

The lecture intends to provide a deep understanding on research-oriented topics of hadron physics. Basic concepts as well as topical research topics will be presented. The lecture will provide the essential knowledge necessary to successfully complete an experimental master's thesis in related fields.

Course content

Current experimental methods, electromagnetic and hadronic probes, polarization experiments; resonances, decays, form factors and structure functions of hadrons; effective theories; spectroscopy, symmetry and structures of hadrons, the impact of hadron physics on precision tests of the Standard Model. Key experiments will be discussed for all topics.

Applicable to the following programs

MSc. Physics

Recommended prerequisites

Knowledge at the level of Experimental Physics 5 “Nuclear and Particle Physics”.

Entry requirements

Mode and duration of examinations

8.1. Active participation

successful completion of the exercises

8.2. Course achievements

8.3. Module examination

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

Weighting of the achievement in the overall grade

6/120

Persons responsible for this module and full-time lecturers
Module Advanced Course: „Advanced Chapters on Subatomic Physics“

Responsible: Prof. Dr. A. Denig
Lecturers: from the field of experimental nuclear and particle physics

Auxiliary Information
Course language:
11. German or English on request
Literature: Several text books, e.g.
- B. Povh et al., Particles and Nuclei
- D. H. Perkins, High Energy Physics
- W. Thomas and W. Weise, The Structure of the Nucleon

Module Advanced Course: „Advanced Astroparticle- and Astrophysics“

ID number 08.128.808  Workload Duration of Course Designated term Credit Points

| 180 h | 1 Semester | 2. Semester | 6 LP |

1. Courses/Teaching methods
Lectures with exercises
„Advanced Astroparticle- and Astrophysics“ (WP)

Lectures (WP) 138 h 6 LP
Exercises (WP)

2. Group sizes
Lecture: unlimited
Exercise: 20

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

4. Course content
Depending on interest of the lecturer, the emphasis will be put on nuclear- or astrophysical aspects of the following subjects:
- Cosmology (early universe, nucleosynthesis, dark components),
- Stars (formation, energy production and development stages) or
- Cosmic radiation (origin, acceleration mechanisms, etc.).

5. Applicable to the following programs
MSc. Physics

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

7. Entry requirements

8. Mode and duration of examinations
8.1. Active participation
successful completion of the exercises

8.2. Course achievements

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

9. Weighting of the achievement in the overall grade
6/120
### Module Advanced Course: „Advanced Astroparticle- and Astrophysics“

10. Frequency of the module offering

11. Persons responsible for this module and full-time lecturers
   
   Responsible: Prof. Dr. L. Köpke
   
   Lecturers: Prof. S. Böser, Apl Prof. Dr. Egelhoff, Apl Prof. Dr. Kabuss, Prof. Dr. Köpke, Prof. Dr. Oberlack, Prof. Dr. Wurm

12. Auxiliary Information
   
   Course language: German or English on request
   
   Literature:
   
   - C. Grupen, Astroteilchenphysik
   - E. Rolfs und W. Rodney, Cauldrons in the Cosmos

### Module Advanced Course: „Advanced Accelerator Physics“

<table>
<thead>
<tr>
<th>ID number 08.128.816</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 h</td>
<td>1 Semester</td>
<td>2. Semester</td>
<td>6 LP</td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
   
   **Lecture with exercises
   „Advanced Accelerator Physics“ (WP)**
   
   **Lectures (WP)**
   
   3 SWS/31.5 h
   
   **Excercises (WP)**
   
   1 SWS/10.5 h

2. Group sizes
   
   Lecture: unlimited
   
   Excercise: 20

3. Qualification and program goals/Competences
   
   The first objective of the course is to understand spin-polarized ensembles. Later-on, we will discuss their behavior under the conditions of relativistic motion in macroscopic external fields. This regime is governed by the Thomas-BMT equation. The spin dynamics in spin rotators, recirculating linear accelerators, but also in particular for synchrotrons and storage rings will be discussed.

   The second part is devoted to the realization of spin-sensitive experiments at accelerators which are of course based on the interaction of spins with microscopic fields. Information on these interactions may be obtained by measuring spin sensitive observables, e.g. the analysing power of the process. The presentation of experimental techniques such as polarized sources and polarimeters concludes the course. The course provides the background successfully complete an master’s thesis in the groups at MAMI that deal with experiments based on spin-polarized beams.

4. Course content
   
   The course will provide knowledge and competence with respect to the following subjects:
   
   Spin polarized ensembles, density matrix, Dirac equation, spin precession in the lab frame (Thomas BMT equation), single pass spin rotators, sibirian snakes, intrinsic and imperfection resonances in storage rings, Sokolov-Ternov effect, spinstable solutions, depolarization by synchrotron radiation, spin equilibrium, spin polarized sources, spin sensitive observables (analyzing powers), polarimetry parity violating observable
   
   Parity violation experiments at accelerators, double polarization experiments with polarized targets at collider facilities.

5. Applicable to the following programs
   
   MSc. Physics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations
<table>
<thead>
<tr>
<th>Module Advanced Course: „Advanced Accelerator Physics“</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>8.1. Active participation</strong></td>
</tr>
<tr>
<td>successful completion of the exercises</td>
</tr>
<tr>
<td><strong>8.2. Course achievements</strong></td>
</tr>
<tr>
<td><strong>8.3. Module examination</strong></td>
</tr>
<tr>
<td>Written exam (90-180 Min.) or oral examination (30 Min.)</td>
</tr>
<tr>
<td><strong>9. Weighting of the achievement in the overall grade</strong></td>
</tr>
<tr>
<td>6/120</td>
</tr>
<tr>
<td><strong>10. Frequency of the module offering</strong></td>
</tr>
<tr>
<td>Every summer semester</td>
</tr>
<tr>
<td><strong>11. Persons responsible for this module and full-time lecturers</strong></td>
</tr>
<tr>
<td>Responsible: Prof. Dr. K. Aulenbacher</td>
</tr>
<tr>
<td>Lecturers: Docents representing the area</td>
</tr>
<tr>
<td><strong>12. Auxiliary Informations</strong></td>
</tr>
<tr>
<td>Course language:</td>
</tr>
<tr>
<td>German or English on request</td>
</tr>
<tr>
<td>Literature:</td>
</tr>
</tbody>
</table>
### 4.5 Research Phase

#### Module Specialization

<table>
<thead>
<tr>
<th>ID number M.08.128.660</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>420 h</td>
<td>1 Semesters</td>
<td>3. Semester</td>
<td>14 LP</td>
</tr>
</tbody>
</table>

1. **Courses/Teaching methods**  
   - **Specialization (P)**  
     - Contact time: 60 h  
     - Self-study: 360 h  
     - Credit Points: 14 LP

2. **Group sizes**

3. **Qualification and program goals/Competences**  
   Within a working group the lecture intends to provide the student with  
   - the special knowledge necessary to successfully complete a master's thesis and the  
   - necessary methods to successfully complete a master’s thesis and to work independently on a specific scientific topic.

4. **Course content**  
   A preliminary topic of the master’s thesis from the research project of an experimental or theoretical working group will be specified which the student will then begin to work on.

5. **Applicable to the following programs**  
   - MSc. Physics

6. **Recommended prerequisites**

7. **Entry requirements**  
   All teaching units of the master’s courses from the 1st and 2nd semester, with the possible exception of the Special Lecture II, the Advanced Lecture and Seminar II.

8. **Mode and duration of examinations**  
   8.1. **Active participation**  
   Working on the research project with at least one weekly supervising discussion.  
   8.2. **Course achievements**  
   8.3. **Module examination**  
   A concluding presentation to the working group.

9. **Weighting of the achievement in the overall grade**  
   0/120 (the module does not enter in the overall grade)

10. **Frequency of the module offering**  
    - Year round

11. **Persons responsible for this module and full-time lecturers**  
    Responsible: Prof. Dr. M. Ostrick  
    Lecturers: All lecturers in physics

12. **Auxiliary Information**  
    - Course language:  
      - German or English

### Module Methodological Knowledge

<table>
<thead>
<tr>
<th>ID number M.08.128.670</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
</table>
Module Methodological Knowledge

<table>
<thead>
<tr>
<th>Courses/Teaching methods</th>
<th>Contact time</th>
<th>Self-study</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodological Knowledge (P)</td>
<td>60 h</td>
<td>390 h</td>
<td>15 LP</td>
</tr>
</tbody>
</table>

26. Group sizes

27. Qualification and program goals/Competences

Within a working group the lecture intends to provide the student with
- the special knowledge necessary to successfully complete a master’s thesis and the
- methods necessary to successfully complete a master’s thesis and to work independently on a specific scientific topic.

28. Course content

For the topic of the master’s thesis from the research project of an experimental or theoretical working group, the student will become familiar with the methods necessary to complete the master’s thesis.

29. Applicable to the following programs

MSc. Physics

30. Recommended prerequisites

31. Entry requirements

Module „Specialization“

32. Mode and duration of examinations

8.1. Active participation

Learning the methods in addition to at least one weekly supervising discussion

8.2. Course achievements

8.3. Module examination

Based on a concluding presentation to the working group or creating a portfolio

33. Weighting of the achievement in the overall grade

15/120

34. Frequency of the module offering

Year round

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

Responsible: Prof. Dr. M. Ostrick
Lecturers: All lecturers in physics

36. Auxiliary Information

Course language:
- German or English

Module Master’s Thesis

<table>
<thead>
<tr>
<th>ID number M.08.128.960</th>
<th>Workload</th>
<th>Duration of Course</th>
<th>Designated term</th>
<th>Credit Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 h</td>
<td>1 Semester</td>
<td>4. Semester</td>
<td>15 LP</td>
<td></td>
</tr>
</tbody>
</table>

1. Courses/Teaching methods
Module Master’s Thesis

<table>
<thead>
<tr>
<th>a) Master’s Thesis (P)</th>
<th>112 h</th>
<th>788 h</th>
<th>30 LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>b) Final Colloquium (P)</td>
<td>2 h</td>
<td>28 h</td>
<td>1 LP</td>
</tr>
</tbody>
</table>

2. Group sizes

3. Qualification and program goals/Competences

4. Course content
   For the topic of the master’s thesis from the research project of an experimental or theoretical working group, the student will develop new results at the frontiers of knowledge.

5. Applicable to the following programs
   MSc. Physics

6. Recommended prerequisites

7. Entry requirements
   Module „Specialization“ and „Methodological Knowledge“ of the research phase

8. Mode and duration of examinations
   8.1. Active participation
   Developing the new results at the frontiers of knowledge with at least one weekly supervising discussion
   8.2. Course achievements
   Written master’s exam
   8.3. Module examination
   Final colloquium in front of the working group or a wider audience

9. Weighting of the achievement in the overall grade
   30/120 (see § 16 of the PO)

10. Frequency of the module offering
    Year round

11. Persons responsible for this module and full-time lecturers
    Responsible: Prof. Dr. M. Ostrick
    Lecturers: All lecturers in physics

12. Auxiliary Information
    Course language:
    - German or English

4.6 SUBSIDIARY SUBJECTS
Currently only the lectures from the Economics subject are always in English. For the other subsidiary subjects it is up to the lecturer to decide about the course language. The description of the individual courses (in German) can be found in the German version of this document for now until they are fully translated.