Modulhandbuch
M.Sc. Physics

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Module und Modulgruppen

Advanced Theoretical Physics

Module Description

Module name **Advanced Quantum Mechanics**					
Module no. 05-22-1422	**Credit Points** 7 CP	**Workload** 210 h	**Self-study** 135 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Hans-Werner Hammer		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1422-vl	Advanced Quantum Mechanics	0	Lecture	3
05-23-1422-ue	Advanced Quantum Mechanics	0	Übung	2

2 Study Content

Advanced quantum mechanics:
Scattering in quantum mechanics, formal scattering theory, path integral methods.

Many-particle quantum mechanics:
Symmetric and antisymmetric many-body states, second quantisation, approximation methods.

Relativistic quantum mechanics:
Recall of spec. relativity, Klein-Gordon equation, Dirac equation, applications from atomic physics.

3 Learning Outcomes

The students
- have in-depth knowledge of advanced concepts, terms and methods of quantum mechanics, for example relativistic quantum mechanics, basic topics of quantum field theory or many-particle theory as well as the application of these models to electrodynamic problems
- possess in-depth skills in the theoretical treatment and formulation of mathematical-physical approaches for the description of complex quantum mechanical problems, so that tasks in the above-mentioned fields can be solved
can be processed with the theoretical methods learned and are competent in the independent processing of problems in the above-mentioned subject areas.
- are able to embed the subject-related contents in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) oral examination 30 min, from 25 participants a written examination of 120 min can be given. The form of examination will be announced in the first two weeks of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** Mandatory module in M.Sc. Physics
9	**Literature** to be specified by the professor
10	**Comment**

Seminars

Here you will find a selection of seminars.
The current offer, which is constantly being expanded according to the current research areas, can always be found in the respective semester in TUCaN.

Module Description

Module name **Laser physics and laser technology**						
Module no. 05-27-2022	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Infrequent	
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. Thomas Halfmann			

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2022-se	Laserphysik und Lasertechnologie (Experimentell)	0	Seminar	2

2 Study Content

Current, changing topics in the fields of laser physics, laser optics, and laser technology, i.e. the technical implementation and application of coherent light sources

3 Learning Outcomes

The students

- know foundations, methods, implementations and applications of modern laser physics, laser optics and laser technology
- know presentation techniques and principles of scientific discussion,
- have the skills to work independently on a defined experimental topic in consultation with a supervisor, to fathom out the physical facts and to present them clearly to a student audience, and
- are competent in independent work, presentation and discussion at a scientific level.
- possess the ability to critically reflect on and discuss research findings.

4 Requirements for Participation

none

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** is issued by lecturer on specific topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

<table>
<tr><td colspan="7">Module name

Symmetries in Theoretical Physics</td></tr>
<tr><td>Module no.
05-27-2023</td><td>Credit Points
5 CP</td><td>Workload
150 h</td><td>Self-study
120 h</td><td>Duration
1 Semester</td><td colspan="2">Frequency
Summer semester</td></tr>
<tr><td colspan="3">Language of Instruction
Deutsch und Englisch</td><td colspan="4">Person responsible for the Module
Prof. Dr. rer. nat. Jens Braun</td></tr>
<tr><td>1</td><td colspan="6">Courses of the Module
<table>
<tr><th>Course no.</th><th>Course name</th><th>Workload (CP)</th><th>Form of Teaching</th><th>Contact Hours per Week</th></tr>
<tr><td>05-27-2023-se</td><td>Symmetries in Theoretical Physics</td><td>0</td><td>Seminar</td><td>2</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="6">Study Content
-Prepare and give a scientific presentation in the field of modern hadron and particle physics.
-Insights into the hadron spectrum, quantum electrodynamics, quantum chromodynamics, spontaneous symmetry breaking, and the Higgs mechanism will be provided</td></tr>
<tr><td>3</td><td colspan="6">Learning Outcomes
-Independent study of a topic area in theoretical physics.
-Preparation of a presentation of the topic area
-Free presentation of the self-prepared presentation
-Insights into the role of symmetries in modern theoretical physics, with emphasis on hadron and particle physics, Spontaneous symmetry breaking, Gauge theories
-Ability to critically reflect on and discuss research results.</td></tr>
<tr><td>4</td><td colspan="6">Requirements for Participation
None (Recommended Theoretical Physics I-V)</td></tr>
<tr><td>5</td><td colspan="6">Form of Examination
Final Module Examination:
• Module Examination (Study Examination, Presentation, Duration 30 min, Standard)
Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
Active participation in the discussion of the presentations may result in a grade bonus of up to 0.4.</td></tr>
<tr><td>6</td><td colspan="6">Requirements on the Award of Credit Points</td></tr>
</table>

	Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in Master Physics
9	**Literature** T.P. Cheng und L.F. Li: Gauge theory of elementary particle physics S. Coleman: Aspects of Symmetry W. Greiner und B. Müller: Quantenmechanik – Symmetrien D. Griffiths: Introduction to Elementary Particles S. Scherer: Symmetrien und Gruppen in der Teilchenphysik
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Physical Modelling in Radiation Research**					
Module no. 05-27-2025	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Deutsch			**Person responsible for the Module** PD Dr. Thomas Friedrich		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2025-se	Physikalische Modellierung in der Strahlenforschung	0	Seminar	2

2 Study Content

Ionizing radiation can cause great damage in biological matter even at moderate energy depositions. The quantification of such damage is of great importance in radiation protection as well as in radiation therapy for cancer patients. The physical and biological processes involved are complex and occur in a multi-step process on several relevant spatial and temporal scales. In this context, the development of biophysical models aims at a simplified but sufficiently accurate quantification of radiation damage. For example, high weighting factors for ion radiation in the calculation of the effective dose equivalent represent a biophysical model.

The seminar will highlight modeling approaches that allow the determination of radiation damage. After a broad introduction to the topic by the seminar instructors, participants give presentations on selected topics, addressing the steps involved in model building, the underlying assumptions, application, and validation against experimental data. The corresponding methods reflect typical techniques that generally play a role in other areas of physics and applied mathematics in the context of model building. The spectrum of topics ranges from the description of ionization patterns after irradiation to models for damage induction and cell survival to the optimization of dose distributions for use in radiotherapy.

3 Learning Outcomes

The students will get an overview of physical methods and concepts that are relevant in the assessment of biological damage by ionizing radiation. In doing so, the seminar moves thematically in an interdisciplinary field in the entire range between basic research and application, which allows the students different perspectives as well as demands in the preparation of presentations. They acquire the ability to critically reflect and discuss research results.

4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** Hall; Giaccia, Radiobiology for the radiologist, 8th edition, Wolters Kluwer, Philadelphia (2019). Depending on the subject area, further literature is recommended.
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Many-Body Physics of Nuclei**					
Module no. 05-27-2030	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Ph. D. Achim Schwenk		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2030-se	Many-Body Physics of Nuclei	0	Seminar	2

2 Study Content

The seminar "Many-Body Physics of Nuclei" deals with advanced topics in theoretical nuclear physics. The program of seminar lectures includes topics such as:

1) Many-Body Basis Sets and Optimization
2) Configuration Interaction Methods
3) Eigenvector Continuation
4) Coupled-Cluster Theory
5) In-Medium Similarity Renormalization Group
6) Beta Decay and Two-Body Currents
7) Model-Space Extrapolation and Artificial Neural Networks
8) Bayesian Uncertainty Quantification
9) Nuclear Equation of State and Applications to Neutron Stars
10) Fermi Liquid Theory

3 Learning Outcomes

Independent familiarization with a topic in theoretical physics

Elaboration of a presentation of the topic

Free presentation of the self-prepared presentation

Ability to critically reflect and discuss research results

4 Requirements for Participation

None (Recommended Theoretical Physics I-V, Higher Quantum Mechanics)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in Master Physics
9	**Literature**
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Laser Plasma Physics and Applications of Laser-based Particle and Photon Sources**					
Module no. 05-27-2035	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Markus Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2035-se	Laser Plasma Physics and Applications of Laser-based Particle and Photon Sources	0	Veranstaltung	2

2 Study Content

Modern topics in laser and plasma physics are covered.
Introduction to the physical fundamentals of laser-matter interaction at high intensities.
Presentations on topics in laser and plasma physics (especially laser-based particle and photon sources and their applications).

Typical topics are:
"Proton acceleration with high intensity lasers and applications in radiobiology"
"Electron acceleration in laser-driven wakefields"
"Betatron x-rays from laser-electron accelerators and their applications in x-ray imaging and spectroscopy"
"Inertial confinement fusion with high power lasers"
"Creating extreme states of matter with relevance in astrophysics using laser-solid interactions"
"Laser-based neutron sources and their applications in nondestructive material analysis"
"All-optical gamma ray sources by inverse Compton scattering"
"Generation of attosecond pulses by relativistically oscillating mirrors"

3 Learning Outcomes

The students
know the basics of the physics of laser-produced plasmas and laser-based photon and particle sources
know a current field of research in the field of laser and plasma physics, laser-based particle and photon sources and their applications
know the literature review on a selected topic in the field of laser-based photon and particle sources
are able to present a selected topic in the form of a technical lecture in the English language
have the ability to critically reflect on and discuss research results.

4	**Requirements for Participation** Recommended: basic knowledge of electrodynamics (Physics II) and laser physics
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in the Master Physics
9	**Literature** For the introductory part: P. Gibbon, "Short Pulse Laser Interactions with Matter: An Introduction", Imperial College Press. For the lectures, the literature or scientific publications will be provided by the lecturer.
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

<table>
<tr><td colspan="7">Module name

Current Topics of Structure and Dynamics in Soft Matter</td></tr>
<tr><td>Module no.
05-27-2220</td><td>Credit Points
5 CP</td><td>Workload
150 h</td><td>Self-study
120 h</td><td>Duration
1 Semester</td><td colspan="2">Frequency
Winter semester</td></tr>
<tr><td colspan="3">Language of Instruction
Englisch</td><td colspan="4">Person responsible for the Module
Prof. Dr. rer. nat. Regine von Klitzing</td></tr>
<tr><td>1</td><td colspan="6">Courses of the Module
<table>
<tr><th>Course no.</th><th>Course name</th><th>Workload (CP)</th><th>Form of Teaching</th><th>Contact Hours per Week</th></tr>
<tr><td>05-27-2220-se</td><td>Current Topics of Structure and Dynamics in Soft Matter</td><td>0</td><td>Seminar</td><td>2</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="6">Study Content
Soft matter is characterized by complex structural and dynamical behavior covering a large length and time range. We want to learn about these phenomena, their theoretical description, and the experimental methods required for observation. In addition to acquiring fundamental knowledge, we will also gain insight into current research topics.</td></tr>
<tr><td>3</td><td colspan="6">Learning Outcomes
The students
- are aware of concepts and phenomena of soft matter physics and know experimental methods to investigate these properties, are familiar with presentation techniques and know the basics of scientific discussion,
- possess skills in model building and in the formulation of mathematical-physical approaches and are able to apply these to problems in the above-mentioned areas and to communicate them in a lecture, are able to familiarize themselves independently with a delimited subject area under consultation with a supervisor, to penetrate the physical facts and to present them clearly to a student audience, and
- are competent in presenting and communicating physical relationships and in the use of media, and possess the ability to critically reflect on and discuss research results.</td></tr>
<tr><td>4</td><td colspan="6">Requirements for Participation
Recommended: Basic knowledge of solid state physics is required and soft matter physics</td></tr>
<tr><td>5</td><td colspan="6">Form of Examination
Final Module Examination:
• Module Examination (Study Examination, Presentation, Duration 30 min, Standard)</td></tr>
</table>

	Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** Is given in connection with the respective topics. An overview of "soft matter" is given e.g. by the book R. Jones, Soft Condensed Matter, Oxford Master Series in Condensed Matter Physics.
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Nuclear Structure and Astrophysics (Experiment)**						
Module no. 05-27-2907	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every semester	
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Thomas Aumann			

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1742-se	Nuclear Structure and Nuclear Astrophysics - Experiments	0	Seminar	2

2 Study Content

Radioactive beam production
Ground-state properties of nuclei
Collective properties of nuclei
Nuclear equation of state
Reactions with exotic nuclei
Applications to nuclear astrophysics

3 Learning Outcomes

The students
• know selected deepened topics in nuclear physics and nuclear astrophysics, know presentation techniques and are familiar with the basics of scientific discussion,
• have skills to become acquainted independently with a well-defined scientific topic under consultation of a supervisor, to understand the physics facts and to present them clearly understandable for a student audience, and
• are competent with the independent study, presentation, and discussion on a scientific level, have the ability to critically reflect and discuss research results

4 Requirements for Participation

None (Recommended Physics VI)

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

	Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** Will be given by the lecturer for the selected topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Nuclear Astrophysics**					
Module no. 05-27-2916	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Almudena Arcones Segovia		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2916-se	Nuclear Astrophysics	0	Seminar	2

2 Study Content

Nucleosynthesis in the Big Bang
Basic equations of stellar evolution
Hydrogen burning-
Sun and solar neutrinos
Shell burning, helium burning, higher burning phases
Supernovae
Neutron star fusion and gravitational waves

3 Learning Outcomes

The students

know the basic nuclear physics processes in the universe and their influence on the evolution of astrophysical objects and element synthesis in the universe,

know advanced methods of modern theoretical physics and their application to problems in nuclear astrophysics

know the basics of scientific discussion

have the ability to work independently on a defined topic in consultation with a supervisor, to penetrate the physical issues and to present them clearly to a student audience

are competent in independent processing, presentation and discussion at a scientific level.

possess the ability to critically reflect on and discuss research findings.

4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in the Master Physics
9	**Literature** will be issued by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Relativistic Heavy Ion Physics (experiment)**					
Module no. 05-27-2921	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. phil. nat. Tetyana Galatyuk		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2422-se	Relativistic Heavy Ion Physics	0	Seminar	2

2 Study Content

Alternating actual topics from the field of relativistic heavy ion physics, e.g.

- quarks, gluons, and hadrons
- kinematics of relativistic heavy ion collisions
- electromagnetic probes
- quarkonia and open heavy flavor
- hard probes and jets
- collective flow

3 Learning Outcomes

The students

- know concepts and techniques on how to extract various signals from high energy heavy-ion collisions and interpret them
- are competent in the independent processing of tasks in the above-mentioned subject areas
- are able to work independently on a selected topic in consultation with a supervisor and present this to a student audience

	• can competently answer questions about their own lecture and, on the basis of the knowledge acquired, actively participate in scientific discussions and drive these forward with their own questions
4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Presentation, Duration 30 min, Standard) Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Relativistic Heavy Ion Physics (theory)**					
Module no. 05-27-2922	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Ph.D. Guy Moore		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-2422-se	Relativistic Heavy Ion Physics	0	Seminar	2

2 Study Content

- quarks, gluons, and hadrons
- kinematics of relativistic heavy ion collisions
- electromagnetic probes
- quarkonia and open heavy flavor
- hard probes and jets
- collective flow

3 Learning Outcomes

The students
know concepts of theoretical description and modeling of heavy-ion collisions and signals measured in the process as well as their foundations in the Standard Model, in particular the theory of the strong interaction,
are able to work independently on a defined topic in consultation with a supervisor and present this to a student audience in the context of a lecture,
can competently answer questions concerning their own presentation and, on the basis of the acquired knowledge, actively participate in scientific discussions and advance these discussions by asking their own questions.
possess the ability to critically reflect on and discuss research results.

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

	Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in the Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Statistical Physics of Networks**					
Module no. 05-27-2930	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. rer. nat. Barbara Drossel		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1010-se	Theorie von Netzwerken	0	Seminar	2

2 Study Content

- Structural characteristics of networks
- Small-world networks
- Scale-free networks
- Dynamics on Boolean random networks
- Growth of networks

3 Learning Outcomes

The students

- get an overview of the physics of networks; the structure, dynamics and evolution of networks are discussed, they know presentation techniques and are familiar with the basics of scientific discussion,
- have the ability to work independently on a specific topic in consultation with a supervisor, to understand the physics involved and to present it clearly to a student audience, and
- are competent in independent processing, presentation, and discussion at a scientific level and are given the ability to critically reflect on and discuss research findings.

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.

6 Requirements on the Award of Credit Points

	Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in the Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Quantum Information - Development, Protocols, Technologies – Experiments**					
Module no. 05-27-2961	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. Thomas Walther		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1141-se	Quantum Information - Development, protocols, technologies	0	Seminar	2

2 Study Content

Bell's inequalities, entangled quantum states, quantum mechanical processes, experimental aspects of teleportation, quantum computing (basic algorithms, experimental approaches, universal quantum gates), quantum cryptography (basic quantum protocols, single photon light sources).

3 Learning Outcomes

The students
- are familiar with a current research topic in the field of experimental quantum information by independent literature study, and are familiar with common methods in the field of quantum information and know about important applications of these methods
- possess skills in analyzing current research topics in the field of experimental quantum information and communicating the acquired knowledge, and
- are competent in working independently on problems in the aforementioned subject area and possess the ability to critically reflect on and discuss research results.

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.

6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Quantum Information - Development, Protocols, Technologies – (Theory)**					
Module no. 05-27-2962	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. Gernot Alber		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1141-se	Quantum Information - Development, protocols, technologies	0	Seminar	2

2 Study Content

Examples include Bell's inequalities, entangled quantum states, quantum mechanical processes, theoretical aspects of teleportation, quantum computing (basic algorithms, universal quantum gates), quantum cryptography (basic quantum protocols, single photon light sources).

3 Learning Outcomes

The students
- are familiar with a current research topic in the field of experimental quantum information by independent literature study, and are familiar with common methods in the field of quantum information and know about important applications of these methods
- possess skills in analyzing current research topics in the field of experimental quantum information and communicating the acquired knowledge, and
- are competent in working independently on problems in the aforementioned subject area and possess the ability to critically reflect on and discuss research results.

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.

6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in the Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Cold Atoms - From the Beginnings to Applications (Theory)**					
Module no. 05-27-2963	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. Reinhold Walser		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1982-se	Cold Atoms - From the Beginnings to Applications	0	Seminar	2

2 Study Content

Fundamentals of laser cooling, cooling methods, traps, atomic lasers, optics and interferometry, Bose-Einstein condensation, optical gratings, photo-association, cold Fermigase

3 Learning Outcomes

The students
- are familiar with a current research topic in the field of theoretical cold atom physics through independent study of the literature, and are familiar with common methods in the field of cold atoms and know about important applications of these methods
- possess skills in analyzing current research topics in the field of theoretical cold atom physics and communicating the acquired knowledge, and
- are competent in working independently on problems in the aforementioned subject area and possess the ability to critically reflect on and discuss research results..

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.

6 Requirements on the Award of Credit Points

Passed examination

7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Theoretical Physics Seminar in the Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Module Description

Module name **Cold Atoms - From the Beginnings to Applications (Experiments)**					
Module no. 05-27-2964	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Deutsch			**Person responsible for the Module** Dean of Studies		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-27-1982-se	Cold Atoms - From the Beginnings to Applications	0	Seminar	2

2 Study Content

Fundamentals of laser cooling, cooling methods, traps, atomic lasers, optics and interferometry, Bose-Einstein condensation, optical gratings, photo-association, cold Fermigase

3 Learning Outcomes

The students
- are familiar with a current research topic in the field of experimental cold atom physics by independent literature study, and are familiar with common methods in the field of quantum information and know about important applications of these methods
- possess skills in analyzing current research topics in the field of experimental cold atom physics and communicating the acquired knowledge, and
- are competent in working independently on problems in the aforementioned subject area and possess the ability to critically reflect on and discuss research results.

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Presentation, Duration 30 min, Standard)

Details of the presentation (30 min) will be announced by the lecturers at the beginning of the course.

6 Requirements on the Award of Credit Points

Passed examination

7	**Grading** Final Module Examination: • Module Examination (Study Examination, Presentation, Weight: 100%, Standard)
8	**Usability of the Module** Experimental Physics Seminar in Master Physics
9	**Literature** will be given by lecturer on the concrete topics
10	**Comment** The presence at the presentations of the other seminar participants is useful in order to actively participate in the discussion and to achieve the qualification goal: "Ability to critically reflect and discuss research results.”

Specialisation

Module Description

Module name					
Focus Nuclear Physics and Nuclear Astrophysics					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
05-21-1357	13 CP	390 h	270 h	2 Semester	Every semester
Language of Instruction			**Person responsible for the Module**		
Englisch			Prof. Dr. Achim Schwenk		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3282-vl	Theoretical Nuclear Physics	0	Lecture	3
05-21-3421-vl	Experimental Nuclear Physics	0	Lecture	3
05-23-3282-ue	Theoretical Nuclear Physics	0	Übung	1
05-23-3421-ue	Experimental Nuclear Physics	0	Übung	1

2 Study Content

Specialization Nuclear Physics and nuclear Astrophysics

Theoretical nuclear physics:
Hilbert space of the nuclear many-body problem,
Nucleon-nucleon interaction,
Deuteron and nucleon-nucleon scattering,
Fermi gas model and shell model,
Hartree-Fock approximation, ground state properties and collective excitations,
Effective interactions,
Modern methods of nuclear structure theory

Experimental nuclear physics:
Building blocks of matter,
Nuclear Physics with radioactive beams,
Radioactive Beam Production,
Ground-state properties of nuclei,
Collective properties of nuclei,
Nuclear equation of state and symmetry energy,
Connections to nuclear astrophysics

3 Learning Outcomes

The students
- know the basic theoretical concepts and methods of nuclear structure physics. They know about

	models for the description of nuclear properties, their microscopic origin and their areas of application, e.g. shell model, Hartree-Fock approximation, and random phase approximation, - have skills in the theoretical treatment and the formulation of mathematical-physical approaches for the description of the nuclear many-particle problem, so that tasks in the mentioned areas can be processed with the learned theoretical methods, - are competent in the independent processing of problems in the above-mentioned subject areas and are able to understand the application possibilities and validity limits of nuclear physics models and methods. of nuclear physics models and methods. The students - know in depth terms, concepts and methods of nuclear and elementary particle physics and know about the structure of atomic nuclei and particles, they know the building blocks of matter and have a phenomenological understanding of the underlying interactions and the experiments to investigate the structure, - have skills to describe, understand and apply the concepts, methods and experiments to problems and to communicate the knowledge acquired, and - are competent in the independent processing of tasks in experimental nuclear and particle physics. The students - are in particular able to network the knowledge, skills and competences taught in the two lectures and apply them to experimental and theoretical problems in nuclear and particle physics.
4	**Requirements for Participation** None (Recommended Physics VI)
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 60 min, Standard)
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** MSc Physics, for the specialisation - Nuclear Physics and Nuclear Astrophysics.
9	**Literature** To be announced during the course, for example

	Ring, Schuck: The Nuclear Many-Body Problem Bohr, Mottelson: Nuclear Structure (Vol. 1 u. 2) Greiner, Theoretische Physik Bd. 10: Kernphysik Henley, Garcia: Subatomic Physics Perkins: Introduction to High-Energy Physics
10	**Comment**

Module Description

Module name					
Focus High Energy Density in Matter					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
05-21-1355	13 CP	390 h	270 h	2 Semester	Every semester
Language of Instruction			**Person responsible for the Module**		
Englisch			Prof. Dr. rer. nat. Markus Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1481-vl	Intense Laser Beams	0	Lecture	3
05-21-3212-vl	Ions and Atoms in Plasmas	0	Lecture	3
05-23-1481-ue	Intense Laser Beams	0	Übung	1
05-23-3212-ue	Ions and Atoms in Plasmas	0	Übung	1

2 Study Content

Intense Laser Beams:
Laser Materials, Special aspects of high energy lasers, Non-linear refraction index and B-integral, Modern laser concepts, architecture, pulse shaping, Short-pulse and CPA- lasers, Laser-plasma interaction, Ultra-intense laser matter interaction, Diagnostics of relativistic laser plasmas, Harmonic generation, Particle acceleration

3 Learning Outcomes

The students:
• know the use and properties of different laser materials
• can explain modern laser architecture and their specifics
• know the special aspects of high-energy laser systems
• have a profound understanding in the design and use of short pulse CPA lasers, their characterization and the use of lasers in basic science experiments

4 Requirements for Participation

None (Recommended Physics V)

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 60 min, Standard)

6 Requirements on the Award of Credit Points

Passed examination

7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** MSc Physics for the specialization "H" - High Energy Density in Matter
9	**Literature** To be announced during the course, for example Beispiele: Chen: Introduction into Plasma Physics and controlled Fusion, Vol.1 William Kruer: The principles of laser plasma interactions S. Elizier: The Interaction of High-Power Lasers with Matter W. Koechner: Solid State Laser Engineering A.E. Siegman: Lasers
10	**Comment**

Module Description

Module name **Individual Focus / Specialisation**					
Module no. 05-29-0002	**Credit Points** 13 CP	**Workload** 390 h	**Self-study** 270 h	**Duration** 2 Semester	**Frequency** Every semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Hans-Werner Hammer		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
	Lectures Theoretical Physics	0	Lecture	3
	Lectures Experimental Physics	0	Lecture	3
		0	Übung	1
		0	Übung	1

2 Study Content

The contents are defined according to those in the approved request for specialization.

3 Learning Outcomes

The students

- have in-depth knowledge of advanced concepts, terms and methods.

- know theoretical and experimental methods and are competent in the independent processing of problems in the selected subject areas.

- have skills to describe, understand and apply the concepts, methods and experiments to problems and to communicate the knowledge acquired.

- are competent in the independent processing of tasks in the selected specialisation, and

- are in particular able to connect the knowledge, skills and competences taught in the two lectures and apply them to experimental and theoretical problems in the selected specialisation.

4 Requirements for Participation

None

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 60 min, Standard)

6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** MSc Physics
9	**Literature** To be announced during the course,
10	**Comment**

Compulsory Optional Subjects from Physics and Elective Physics Course

Here you will find a selection of Compulsory Optional Subjects and physics electives.
The current offer, which is constantly expanded according to the current research areas, can always be found in the respective semester in TUCaN.

Module Description

Module name					
Experimental Physics of Condensed Matter					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
05-21-1440	5 CP	150 h	90 h	1 Semester	Winter semester
Language of Instruction			**Person responsible for the Module**		
Deutsch			Prof. Dr. Regine von Klitzing		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3312-vl	Experimental Condensed Matter Physics	0	Lecture	3
05-23-3312-ue	Experimental Condensed Matter Physics	0	Übung	1

2 Study Content

Superconductivity
Dielectric solids and liquids
Alloys, mixtures; glasses
Polymer solids
Liquid crystals, colloidal dispersions

3 Learning Outcomes

The students
- know the phenomena and physical models of superconductivity, know the physical processes that contribute to the dielectric properties, know concepts of structural description and dynamics of partially ordered systems
- possess skills in model building and in the formulation of mathematical-physical approaches and are able to apply to problems in the above areas and communicate them,
- are competent in working independently on problems in the above-mentioned areas and are able to assess the accuracy of observation and analysis.
- are able to embed the technical content in the social context, critically assess the consequences and

	act ethically and responsibly accordingly.
4	**Requirements for Participation** None (Recommended Physics V)
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed Examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter".
9	**Literature** To be announced during the course, for example Ibach/Lüth: Festkörperphysik Strobl: Physik kondensierter Materie Jones: Soft Condensed Matter
10	**Comment**

Module Description

Module name **Atoms and Ions in Plasma**					
Module no. 05-21-1460	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Markus Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3212-vl	Ions and Atoms in Plasmas - Introduction to Plasma Physics with Heavy-Ions	0	Lecture	3
05-23-3212-ue	Ions and Atoms in Plasmas - Introduction to Plasma Physics with Heavy-Ions	0	Übung	1

2 Study Content

Generation and characterization of plasmas and
Plasma parameters
impact ionization, coulomb shocks, conductivity
Waves in plasmas
Kinetic plasma theory
Land attenuation
Saha equation / Beam
Target Interaction
Plasma diagnostics

3 Learning Outcomes

The students
- know the basic concepts of plasma physics, the generation of plasmas and the methods for measuring plasma parameters. They can distinguish between the concepts of ideal plasmas and plasmas with strong coupling parameter.
- are familiar with the main applications of plasma physics in magnetic fusion and inertial fusion,
- possess skills to use different methods of plasma diagnostics, they can estimate the degree of ionization of plasmas and calculate the motion of plasmas under the influence of magnetic fields and make statements about the stability or instability of plasma inclusions.

The students
- are able to analyze aspects of hydrodynamics, atomic physics in plasmas and strong fields, as well as the interaction of intense particle beams and lasers with matter with regard to applications in the

	generation of dense plasmas, make quantitative estimates of important parameters and apply them to experimental problems, as well as communicate the acquired knowledge. - are competent in the independent processing of problems in the above-mentioned subject areas and are able to assess possible applications of the acquired methods of plasma physics and here in particular of plasma physics with heavy ions. - are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.
4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral Examination, Duration 30 min, Passed / Not Passed)
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics".
9	**Literature** To be announced during the course, for example J.A. Bittencourt: Fundamentals of Plasma Physics R.O. Dendy, Plasma Physics
10	**Comment**

Module Description

Module name **Experimental nuclear physics**					
Module no. 05-21-1465	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Thomas Aumann		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3421-vl	Experimental Nuclear Physics	0	Lecture	3
05-23-3421-ue	Experimental Nuclear Physics	0	Übung	1

2 Study Content

Building blocks of matter,
Nuclear Physics with radioactive beams,
Radioactive Beam Production,
Ground-state properties of nuclei,
Collective properties of nuclei,
Nuclear equation of state and symmetry energy,
Connections to nuclear astrophysics

3 Learning Outcomes

The students
- know in depth the terms, concepts and methods of nuclear physics and know about the structure of atomic nuclei, they know the building blocks of matter and have a phenomenological understanding of the underlying interactions and the experiments to investigate the structure,
- have skills to describe, understand and apply the concepts, methods and experiments to problems and to communicate the knowledge acquired,
- are competent in the independent processing of tasks in experimental nuclear physics, and
- are able to embed the technical content in the social context, critically assess the consequences and act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics VI)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "H: High Energy Density in Matter".
9	**Literature** To be announced during the course, for example Henley, Garcia, Subatomic Physics Perkins, Introduction to High-Energy Physics
10	**Comment**

Module Description

Module name **Modern Optics**					
Module no. 05-21-1480	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. rer. nat. Gerhard Birkl		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3052-vl	Moderne Optik	0	Lecture	3
05-23-3052-ue	Moderne Optik	0	Übung	1

2 Study Content

Interaction of radiation and atoms
Resonance fluorescence
Laser cooling
Traps for atoms and ions
Bose-Einstein condensation
Quantum information processing with atoms
Applications to the respective topics

3 Learning Outcomes

The students
- know the basics of modern optics
- have skills in formulating mathematical-physical approaches to modern optics and are able to apply to problems in the mentioned field and communicate them, and
- are competent in independently working on problems in the mentioned fields and possible applications.
- are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics III)

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, oral / written Examination, Passed / Not Passed)

	The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or " H: High Energy Density in Matter"
9	**Literature** To be announced during the course, for example H-A. Bachor: A Guide to Experiments in Quantum Optics; J. Weiner, P.-T. Ho: Light-Matter Interaction
10	**Comment**

Module Description

Module name **Laser spectroscopy on Accelerator equipment/installations**					
Module no. 05-21-2400	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Wilfried Nörtershäuser		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2400-vl	Laser Spectroscopy of Exotic Systems	0	Lecture	3
05-23-2400-ue	Laser Spectroscopy of Exotic Systems	0	Übung	1

2 Study Content

Production of exotic systems, preparation for laser spectroscopy (cooling and trapping techniques), laser spectroscopy techniques

Spectroscopy of hydrogen-like systems: hydrogen, myonic atoms, antimatter, positronium and other atom-like systems with exotic components, CPT theorem, Penning traps, magnetic traps for atoms.

Techniques for laser spectroscopy of highly charged ions at storage rings and in ion traps: storing and cooling highly charged ions in storage rings, fluorescence spectroscopy, Paul trap, logical spectroscopy, highly charged ions and their relevance for tests of quantum electrodynamics in strong fields, Ives-Stilwell test of special relativity.

Applications of laser spectroscopy for nuclear physics studies: production of short-lived isotopes, isotopic shift, magnetic and electrical hyperfine structure, collinear laser spectroscopy, resonance ionization, trapping of atoms and ions, optical pumping, beta-asymmetry, halo nuclei, isomers, laser spectroscopy of super heavy elements.

Basics of the electroweak interaction, Parity violation in atoms, laser spectroscopy for the determination of the weak charge and the nuclear anapole moment.

Search for electric dipole moments (EDM) in atoms and molecules, physics, CP-Violation, Breit-Rabi-Technique, optical detection of spin precession.

3 Learning Outcomes

The students

- know important methods of laser spectroscopy that are used in experiments at accelerators and exotic systems. They know about applications of laser spectroscopy in the field of nuclear and particle physics,

	starting from the underlying physical processes up to the generation of electronically recordable signals. They know common types of detectors, storage and cooling techniques for ions and atoms. - have the skills to analyse laser types and detection systems of laser spectroscopy for experiments in nuclear and particle physics with regard to applications, to make quantitative estimates of important parameters and to apply them to tasks as well as to communicate the acquired knowledge, - are competent in the independent processing of problems in the above-mentioned subject areas and are able to assess the possible applications of laser spectroscopic techniques and measuring equipment, and - are able to embed the technical content in the social context, critically assess the consequences and act ethically and responsibly accordingly..
4	**Requirements for Participation** None (Recommended Physics I - IV, Physics V, and Modern Optics)
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And physics elective for students who have not chosen specialisation "K: Nuclear Physics and Nuclear Astrophysics"
9	**Literature** Lecturer's script, survey articles (no textbook available that covers all subfields), selected professional articles.
10	**Comment**

Module Description

Module name **Physics of Relativistic Heavy Ion Collisions**					
Module no. 05-21-2665	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. phil. nat. Tetyana Galatyuk		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2091-vl	Physics of relativistic heavy ion collisions	0	Lecture	3
05-23-2091-ue	Physics of relativistic heavy ion collisions	0	Übung	1

2 Study Content

Introduction
Kinematics
Accelerators and the design of experiments
Measurement of global observables and the Glauber Model
Nucleon-Nucleon and Nucleus-Nucleus collisions
Collective effects
Thermodynamics
Measurement of hadron yields and the statistical model of particle production at chemical freeze out
Chiral symmetry and the generation of mass
Dilepton spectra at low mass and thermal photons
The physics of charm
Jets and high-momentum particles

3 Learning Outcomes

The aim of this course is overview on physics of nucleus-nucleus collisions at (ultra)relativistic energies with emphasis on experimental results. Exercises in the form of "Journal Club" (presentation and discussion of recent papers) and analysis of the experimental data using ROOT framework - an object oriented data analysis framework
The students

- have an overview of the mechanisms of heavy ion collisions and know the basics of high energy physics

	• know concepts and techniques on how to extract various signals from high energy heavy-ion collisions and interpret them • have the skills to assign and apply the basic terms • are competent in the independent processing of tasks in the above-mentioned subject areas • are able to work independently on a delimited topic in consultation with a supervisor and present this to a student audience • can competently answer questions about their own lecture and, on the basis of the knowledge acquired, actively participate in scientific discussions and drive these forward with their own questions • have the ability to critically discuss research results • are able to embed technical content in the social context, critically assess the consequences and to act ethically and responsibly accordingly.
4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) he type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And physics elective for students who have not chosen specialisation "K: Nuclear Physics and Nuclear Astrophysics"

9	**Literature** F. Halzen and A.D. Martin, "Quarks and leptons: an introductory course in modern particle physics", Wiley, 1984 D. Perkins, Hochenergiephysik, Addison-Wesley, 1991 E.M. Henley and A. Garcia, "Subatomic Physics", World Scientific Publishing, 2007 J. Rafelski and J. Letessier, "Hadrons and Quark-Gluon Plasma", Cambridge University Press
10	**Comment**

Module Description

Module name **Theoretical Nuclear Physics**					
Module no. 05-22-1410	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Hans-Werner Hammer		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-3282-vl	Theoretical Nuclear Physics	0	Lecture	3
05-23-3282-ue	Theoretical Nuclear Physics	0	Übung	1

2 Study Content

Hilbert space of the nuclear many-body problem,
Nucleon-nucleon interaction,
Deuteron and nucleon-nucleon scattering,
Fermi gas model and shell model,
Hartree-Fock approximation, ground state properties and collective excitations,
Effective interactions,
Modern methods of nuclear structure theory

3 Learning Outcomes

The students
- know the basic theoretical concepts and methods of nuclear structure physics. They know about models for the description of nuclear properties, their microscopic origin and their fields of application, e.g. shell model, Hartree-Fock approximation, and random phase approximation,
- have skills in the theoretical treatment and the formulation of mathematical-physical approaches for the description of the nuclear many-body problem, so that tasks in the mentioned areas can be processed with the learned theoretical methods,
- are competent in the independent processing of problems in the mentioned subject areas and are able to assess application possibilities and validity limits of nuclear physics methods,
- are able to embed the technical contents in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

none

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "H: High Energy Density in Matter".
9	**Literature** will be specified by lecturer(s)
10	**Comment**

Module Description

Module name **Condensed Matter Theory**					
Module no. 05-22-1414	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. rer. nat. Barbara Drossel		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2101-vl	Condensed matter theory	0	Lecture	3
05-23-2101-ue	Condensed matter theory	0	Übung	1

2 Study Content

- Many-particle theory for the description of electrons in solids (in particular particle number representation).
- Application of this apparatus to a nontrivial phenomenon (e.g. theory of superconductivity)
- Complementary and optional: selected chapters from higher statistical physics, solid state physics, soft matter theory, and/or continuum mechanics.

3 Learning Outcomes

Students
have a basic understanding of the structure of matter and its dynamics, as well as for modern theoretical concepts for their description.
They are able to work on and communicate complex problems in this field independently and systematically, and to comprehend advanced theoretical literature on the subject.
Students are able to embed the subject content in the social context, critically assess the consequences, and act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics V)

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, oral / written Examination, Passed / Not Passed)

	The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus " K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter ".
9	**Literature** To be announced during the course, for example • Ashcroft/Mermin, Solid State Physics • Ketterson/Song, Superconductivity • Schwabl, Quantenmechanik für Fortgeschrittene • Nolting, Grundkurs Theoretische Physik Bd. 7 • Raimes, Many-Electron Theory • Chaikin/Lubensky, Principles of Condensed Matter Physics
10	**Comment**

Module Description

Module name **Theoretical Particle Physics**					
Module no. 05-22-2610	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Hans-Werner Hammer		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1122-vl	Introduction to Elementary Particle Physics	0	Lecture	3
05-23-3282-ue	Theoretical Nuclear Physics	0	Übung	1

2 Study Content

- Overview of the Standard Model of Elementary Particles
- Symmetries and symmetry breaking
- Quark model of hadrons
- Elements of relativistic quantum mechanics
- Scattering processes and Feynman diagrams
- Deep inelastic scattering and partons

3 Learning Outcomes

The students

- have an overview of the Standard Model of elementary particles, understand the basic mathematical concepts of symmetries and scattering processes, and know the internal structure of hadrons,
- are able to understand and comprehend elements of the mathematical apparatus of theoretical particle physics, and can use it to calculate simple scattering processes of elementary particles, as well as communicate the acquired knowledge,
- are competent in working independently on simple theoretical problems of phenomenological elementary particle physics and can estimate the importance of basic experiments for the development of the Standard Model

and

- are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics VI)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And physics elective for students who have not chosen specialisation "K: Nuclear Physics and Nuclear Astrophysics"
9	**Literature** To be announced during the course, for example Halzen, Martin: Quarks and Leptons
10	**Comment**

Module Description

Module name **Introduction to Astrophysics**					
Module no. 05-22-2623	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. rer. nat. Robert Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-4323-vl	Introduction to Astrophysics	0	Lecture	3
05-23-4323-ue	Introduction to Astrophysics	0	Übung	1

2 Study Content

This introductory lecture gives an overview of modern astrophysics and the underlying theoretical concepts. It covers different aspects of the physics of stars, the interstellar medium, and galaxies as well as selected questions from cosmology. The main topics include:

· Introduction
· Astrophysical Observables
· Electromagnetic Radiation
· Stellar Atmospheres
· Stellar Interiors
· Stellar Evolution and Stellar Remnants
· Interstellar Medium
· Galaxies
· Universe at Larger Scales
· Big Bang Cosmology

3 Learning Outcomes

The students

· know fundamental concepts and theoretical methods in astrophysics, particularly for the description of stellar strucutre and evolution as well as galaxies and large-scale structures,

· are capable of transfering their knowledge from different fields of theoretical physics to the description of astrophysical systems and processes, and are competent in identifying the relevance of observational data and its connection to the underlying physics processes.

4 Requirements for Participation

None (Recommended Physics VI)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And Physics Electives for students "H: High Energy Density in Matter
9	**Literature** · Astrophysics in a Nutshell, D. Maoz (Princeton University Press) · An Introduction to Modern Astrophysics, B. W. Carroll and D. A. Ostlie (Addison Wesley) · Three volumes on Theoretical Astrophysics, T. Padmanabhan (Cambridge University Press) · Theoretical Astrophysics: An Introduction, M. Bartelmann (WILEY-VCH) · Astronomie und Astrophysik: Ein Grundkurs, A. Weigert, H.J.Wendker and L.Wisotzki (WILEY-VCH)
10	**Comment**

Module Description

Module name **Nuclear Astrophysics II**					
Module no. 05-22-2620	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Robert Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2151-vl	Nuclear Astrophysics II	0	Lecture	3
05-23-2151-ue	Nuclear Astrophysics II	0	Übung	1

2 Study Content

Supernova type II
Element synthesis of heavy elements
(s-process. r-process, p-process)
Double star systems
Supernova Type Ia
Novae and X-ray burster
White dwarfs
Neutron stars

3 Learning Outcomes

The students
- Know the basic nuclear physics processes in the universe and their influence on the evolution of astrophysical objects and element synthesis in the universe,
- are able to distinguish the basic processes for the formation of elements in the universe and know the most important nuclear physics information that contributes to these processes,
- are competent to decide independently which nuclear physics data and reactions are fundamentally important for the evolution of astrophysical objects and how to obtain these data, and
- are able to embed the technical content in the societal context, to critically assess the consequences, and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics VI)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And Physics Electives for students "H: High Energy Density in Matter
9	**Literature** • Christian Iliadis: Nuclear Physics of Stars, Wiley-VCH Verlag, Weinheim, 2007 • Bradley W. Carroll and Dale A. Ostlie: An Introduction to Modern Astrophysics, Pearson/Addison-Wesley, San Francisco, 2nd ed. 2007 • S. L. Shapiro and S. A. Teukolsky: Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects, Wiley-Interscience, New York, 1983 • N. K. Glendenning: Compact Stars, Springer Verlag New York Inc., 1997 • Selected review articles
10	**Comment**

Module Description

Module name **Introduction to Quantum Field Theories**					
Module no. 05-22-2625	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. phil. nat. Thorsten Kröll		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2311-vl	Introduction to quantum field theories	0	Lecture	3
05-23-2311-ue	Introduction to quantum field theories	0	Übung	1

2 Study Content

- Classical field theories in Lagrangian formalism, symmetries and conservation quantities.
- Canonical quantization of field theories
- S-matrix in quantum field theory
- Perturbation theory and scattering processes
- Feynman diagram (among other things classification and calculation)

3 Learning Outcomes

The students

- have an overview of basic methods of field quantization, know field types of the Standard Model and their role in the description of scattering processes, and know about the importance of loop diagrams in quantum electrodynamics,
- are able to understand and comprehend elements of the mathematical apparatus of quantum field theories and can use them to calculate scattering processes of elementary particles at the level of loop corrections, as well as communicate the acquired knowledge,
- are competent in working independently on theoretical problems of quantum field theory and, based on this, are able to tackle current research problems, for example in the context of a master's thesis, and
- are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Theoretical Physics II-V)

5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And Physics Electives for students "H: High Energy Density in Matter
9	**Literature** will be specified by lecturer(s)
10	**Comment**

Module Description

Module name **Radiation Biophysics**					
Module no. 05-27-2980	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Dean of Studies		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1662-vl	Radiation Biophysics	0	Lecture	3
05-23-1662-ue	Radiation Biophysics	0	Übung	1

2 Study Content

Physical and biological principles of radiation biophysics, introduction to modern experimental techniques in radiation biology. The interaction of ion beams with biological systems is specifically addressed. All steps required to perform ion beam therapy are presented.
The following areas are discussed: electromagnetic radiation, particle-matter interaction. Biological aspects: Radiation effects of weak ionizing radiation (e.g. X-rays) on DNA, chromosomes, trace structure of heavy ions. (LET: Linear Energy Transfer) Low-LET radiation biology: effects in the cell, high-LET (e.g. ions) radiation biology, physical and biological dosimetry, effects at low dose, ion beam therapy, therapy models, treatment of moving targets.

3 Learning Outcomes

The students are familiar with the physical principles of the interaction of ionizing radiation with matter, its biochemical consequences such as radiation damage in the cell, organs and tissue. Students are familiar with the important applications of radiation biology, e.g., radiation therapy and radiation protection. They are also familiar with the effects of radiation in the environment and in space. The students are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, oral / written Examination, Passed / Not Passed)

	The type of examination is announced at the beginning of the course. It can be either (i) a written examination (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or " H: High Energy Density in Matter"
9	**Literature** To be announced during the course, for example Eric Hall, Radiobiology for the Radiologist, Lippincott Company
10	**Comment**

Module Description

Module name **Atom interferometry**					
Module no. 05-21-2023	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Dean of Studies		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2023-vl	Atom interferometry	0	Lecture	3
05-23-2023-ue	Atom interferometry	0	Übung	1

2 Study Content

-Wave packet dynamics in external fields
-Atom-optical elements and diffraction of matter waves
-Analytical methods for atom interferometer
-Gravimetry, gradiometry and rotation sensing
-Tests of fundamental physics and relativistic effects

3 Learning Outcomes

The students
-know atom-optical methods for the generation of atom interferometers as well as the basic concepts of matter wave interferometry and inertial sensing.
-are able to transfer the gained knowledge to other fields of quantum sensing and quantum technologies and
-possess skills in the theoretical description of cold gases and atom-light interaction, which they can apply independently to other subject areas.
The students are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly

4 Requirements for Participation

none

5 Form of Examination

Final Module Examination:

	• Module Examination (Study Examination, oral / written Examination, Duration 30 min, Passed / Not Passed) The form of examination would be oral 30 min for up to 15 participants, and written 90 min for 16 or more participants.
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or " H: High Energy Density in Matter"
9	**Literature** To be announced during the course, for example H. Rauch and S. A. Werner, "Neutron Interferometry: Lessons in Experimental Quantum Mechanics, Wave-particle Duality, and Entanglement" (Oxford University Press, 2015) G. M. Tino and M. A. Kasevich (eds) "Atom Interferometry" (IOS Press, 2014) T. Byrnes, E. O. Ilo-Okeke, "Quantum Atom Optics: Theory and Applications to Quantum Technology," arXiv2007.146011 [quant-ph] (2020)
10	**Comment**

Module Description

Module name **Medical Physics**					
Module no. 05-23-2019	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Winter semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Marco Durante		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2019-vl	Medical Physics	0	Lecture	3
05-23-2019-ue	Medical Physics	0	Übung	1

2 Study Content

The course covers the applications of physics in medicine, especially in the field of ionising radiation and diagnostic and therapy in oncology.
Following topics will be covered:
X-ray imaging
Nuclear medicine: imaging (SPECT, PET) and therapy with radionuclides
Imaging with non-ionising radiation: ultrasounds, MRI
Radiation therapy
Particle therapy
Radiation protection
Monte Carlo calculations

3 Learning Outcomes

The students are familiar with the principle of physics applications in medicine, especially in radiology and radiotherapy. Know research topics in biomedical physics.
The students are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly

4 Requirements for Participation

None (Recommended “Radiation Biophysics” (Strahlenbiophysik))

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Written Examination, Duration 90 min, Passed / Not Passed)

6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Written Exam, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or " H: High Energy Density in Matter"
9	**Literature** To be announced during the course.
10	**Comment**

Module Description

Module name **Intense Laser Beams**					
Module no. 05-21-2670	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Markus Roth		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1481-vl	Intense Laser Beams	0	Lecture	3
05-23-1481-ue	Intense Laser Beams	0	Übung	1

2 Study Content

Laser media, special aspects of high energy lasers, non-linear refraction index, B-integral, modern laser concepts, architecture, pulse shaping, short pulse and CPA laser, laser plasma interaction diagnostics of relativistic plasmas, generation of high harmonics, particle generation, radiation safety requirements

3 Learning Outcomes

The students
know the basic problems of high-energy and high-power laser systems.
Working individually and using standard literature they can identify the requirements for high energy laser systems and their optimization.
The students can recall the state of the art of modern laser technology.
The students can compare different laser systems and calculate their performance in general.
They can describe the basic laser plasma interaction phenomena and their dependence on the beam parameters.
The students will be able to work on and extend high power laser systems.
The students are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

Recommended Basic knowledge of laser and plasma physics

5 Form of Examination

Final Module Examination:

	• Module Examination (Study Examination, oral Examination, Duration 30 min, Passed / Not Passed)
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics".
9	**Literature** Will be accounced at the beginning of the lecture
10	**Comment**

Module Description

Module name **Theoretical Quantum Optics**					
Module no. 05-22-1412	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Summer semester
Language of Instruction Deutsch			**Person responsible for the Module** Prof. Dr. Gernot Alber		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-1951-vl	Theoretical Quantum optics	0	Lecture	3
05-23-1951-ue	Theoretische Quantenoptik	0	Übung	1

2 Study Content

- Properties and detection of optical radiation
- Interaction between matter and optical electromagnetic waves
- Quantum aspects of optical electromagnetic radiation with applications

3 Learning Outcomes

The students

- know important methods of quantum optics based on the underlying physical processes, know common methods for the investigation of electromagnetic radiation in the optical frequency range and know about important applications of the methods in the field of quantum optics and other fields, such as atomic, molecular or solid state physics,
- have the skills to analyze simple material systems, such as atoms, and their interaction with electromagnetic waves in the optical frequency range and to make quantitative estimates of important parameters and to apply them to problems as well as to communicate the acquired knowledge,
- are competent in working independently on problems in the above-mentioned areas and are able to assess the possible applications of quantum optical methods and
- are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics III)

5 Form of Examination

Final Module Examination:

	• Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written exam (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects and Physics Electives for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or " H: High Energy Density in Matter"
9	**Literature** To be announced during the course, for example L. Mandel, E. Wolf, Optical Coherence and Quantum Optics C. Cohen-Tannoudji, Dupont-Roc, Grynberg, Atom-Photon Interactions W. Demtröder, Laserspektroskopie S. Barnett, Methods in Theoretical Quantum Optics W. Schleich, Quantum Optics in Phase Space
10	**Comment**

Module Description

Module name **Experimental Particle Physics**					
Module no. 05-21-2612	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Deutsch und Englisch			**Person responsible for the Module** Prof. Dr. Thorsten Kröll		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2612-vl	Experimentelle Teilchenphysik	0	Lecture	3
05-23-2612-ue	Experimentelle Teilchenphysik	0	Übung	1

2 Study Content

Standard Model of particle physics, accelerators and detectors, introduction to quantum field theory, hadrons and static quark model, QCD and parton model, weak interaction and electroweak unification, Higgs mechanism, discrete symmetries, neutrinos, astroparticle physics, extensions beyond the Standard Model.

3 Learning Outcomes

The students
- know nuclear physics concepts, phenomena and terms as well as exemplary applications of particle physics,
- possess skills in model building and in the formulation of mathematical-physical approaches and are able to apply to problems in the above-mentioned areas and communicate them,
- are able to work independently and competently on problems in the above-mentioned areas,
- are able to estimate accuracies of observation and analysis and
- are able to embed the technical content in the social context, to critically assess the consequences and to act ethically and responsibly accordingly.

4 Requirements for Participation

None (Recommended Physics I-VI, Theoret. Physics I-III)

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, oral / written Examination, Passed / Not Passed)

	The type of examination is announced at the beginning of the course. It can be either (i) a written exam (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And physics elective for students who have not chosen specialisation "K: Nuclear Physics and Nuclear Astrophysics"
9	**Literature** Script will be provided Literature list will be presented in lecture.
10	**Comment**

Module Description

Module name **Physics of nuclear and particle physics detectors**					
Module no. 05-23-2020	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Infrequent
Language of Instruction Englisch			**Person responsible for the Module** Prof. Dr. Alexandre Obertelli		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
05-21-2020-vl	Physics of nuclear and particle physics detectors	0	Lecture	3
05-23-2020-ue	Physics of nuclear and particle physics detectors	0	Übung	1

2 Study Content

Particle detectors are the key component of any nuclear and particle physics experiment. The lecture aims at a comprehensive overview of main particle detectors used today and the underlying physics mechanisms.

The lecture will be divided in nine topics:
(1) interaction of radiation with mater,
(2) signal formation and readout electronics,
(3) gas detectors,
(4) semiconductors,
(5) scintillators and photomultipliers,
(6) Cerenkov detectors,
(7) multi detectors in particle physics,
(8) detection of weakly interacting particles,
(9) Mossbauer spectrometry for ultra-high-energy resolution.

The spirit of the lecture is to cover each topic from the basics to the state of the art, illustrate by the most recent applications of each detection system. The most relevant physics questions will be introduced.

3 Learning Outcomes

The students
(1) learn how nuclear and particle detectors work,
(2) understand the underlying physics processes and the subsequent limitations,
(3) decide which detection technique is best suited for a given measurement and know the critical

	parameters for a detector, (4) know a variety of today's experiments based on the studied detection techniques (5) are able to embed the technical content in the social context, critically assess the consequences and to act ethically and responsibly accordingly.
4	**Requirements for Participation** none
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) The type of examination is announced at the beginning of the course. It can be either (i) a written exam (K, 90 min), (ii) an oral examination (mP, 30 min), or (iii) a presentation (Pt, 30 min).
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 100%, Passed / Not Passed)
8	**Usability of the Module** MSc Physics: Compulsory Optional Subjects for students of the study focus "K: Nuclear Physics and Nuclear Astrophysics" or "H: High Energy Density in Matter". And physics elective for students who have not chosen specialisation "K: Nuclear Physics and Nuclear Astrophysics"
9	**Literature**
10	**Comment**

Module Description

Module name					
Introduction to Spintronics					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
18-me-2020	6 CP	180 h	120 h	1 Semester	Every 2. semester
Language of Instruction			**Person responsible for the Module**		
English			Prof. Dr. rer. nat. Markus Meinert		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
18-me-2020-ue	Introduction to Spintronics	0	Exercise	1
18-me-2020-vl	Introduction to Spintronics	0	Lecture	3

2 Study Content

The lecture covers the following subjects:

- Basics of atomic physics (structure of the atoms, electron hull)
- Basics of solid state physics (crystalline materials)
- Introduction to electron transport in solids (classical treatment, band structures)
- Basic notions and simple models of magnetism
- Magnetism in thin films
- Spin-dependent electronic transport
- Magnetoresistive effects, anisotropic magnetoresistance
- Giant magnetoresistance (GMR)
- Tunneling magnetoresistance (TMR)
- Spin-Transfer Torque
- Magnetic microwave oscillators
- Spin-Hall effect and other spin-orbit effects
- Materials for spintronics (ferromagnets, antiferromagnets)

	• Magnetic data storage • Spintronic devices as sensors • Magnetic random-access memory (MRAM)
3	**Learning Outcomes** The students learn fundamental concepts of spintronics, from properties of magnetic materials to the design and application of spintronic devices in data storage and magnetic sensing. The students acquire the competence to make use of spintronic devices in applications. They further acquire the competence to understand current scientific literature and to dive deeper into the field.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Duration 120 min, Standard) The examination takes place in form of a written exam (duration: 120 minutes). If one can estimate that less than 16 students register, the examination will be an oral examination (duration: 45 min.). The type of examination will be announced in the beginning of the lecture. Yes
6	**Requirements on the Award of Credit Points**
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module**
9	**Literature** • A script will be made available electronically • Coey, Magnetism and Magnetic Materials, 2009, Cambridge University Press

	• Skomski, Simple Models of Magnetism, 2008, Oxford University Press • Felser, Fecher, Spintronics: From Materials to Devices, 2013, Springer • Dietl, Awschalom, Kaminska, Ohno, Spintronics, 2008, Academic Press • Blachowicz, Ehrmann, Spintronics, 2019, de Gruyter • Tsymbal, Zutic, Spintronics Handbook, Volume One: Metallic Spintronics, 2019, CRC Press • Xu, Awschalom, Nitta, Handbook of Spintronics, 2016, Springer
10	**Comment**

Interdisciplinary Elective Area

General Studies

Module Description

Module name **General Studies (general module description)**					
Module no.	**Credit Points** 10-15 CP	**Workload** 300-450 h	**Self-study**	**Duration** 2 Semester	**Frequency** is determined by the faculty offering the course
Language of Instruction is determined by the faculty offering the course			**Person responsible for the Module**		

1	**Courses of the Module**				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
2	**Study Content** In the General Studies area, students can choose from the catalogs and modules listed in the study and examination plan. This ist he General catalogue of the TU Darmstadt (except General Catalogue Physics) or catalogues provided for Studium Generale. The learning content is based on the individually selected modules and according to the corresponding module descriptions of the offering departments.				
3	**Learning Outcomes** Students create an individual study profile and individually choose their course of study in this elective area according to their own interests. Depending on the student's interests, these may include - interdisciplinary competencies, - language competencies, - key competencies, - knowledge of perspectives and methods from other disciplines				
4	**Requirements for Participation** The regulations of the module descriptions of the departments offering the course apply.				
5	**Form of Examination** The form of examination depends on the regulations in the module descriptions of the offering				

	departments.
6	**Requirements on the Award of Credit Points** The requirement for the award of credit points is based on the regulations in the module descriptions of the offering departments.
7	**Grading** Grading is based on the regulations in the module descriptions of the departments offering the course.
8	**Usability of the Module** MSc Physics
9	**Literature**
10	**Comment** The module description for General Studies is a container module that is added to the module handbooks in order to make this area visible for students and the advising units. The concrete module offer is provided in TUCaN

Elective Area Physics

This optional elective area (0 - 5CP) contains special lectures (see above)

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Research Area

Module Description

Module name **Practical Introduction to Scientific Research**						
Module no. 05-25-5005	**Credit Points** 30 CP	**Workload** 900 h	**Self-study** 900 h	**Duration** 1 Semester	**Frequency** Each. semester	
Language of Instruction Englisch			**Person responsible for the Module** Dean of Studies			
1	**Courses of the Module**					
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**	
2	**Study Content** Getting acquainted with the subject area Getting acquainted with the theoretical and/or experimental working techniques and tools Working on partial aspects Formulation of a work plan and time schedule Documentation of the research question and the sub-aspects worked on by writing a project proposal Presentation of the results in a lecture and scientific discussion					
3	**Learning Outcomes** The students - know the basic questions of a current research area in which they have familiarised themselves, and are familiar with theoretical and/or experimental methods and working and processing techniques for the research area. They are experienced in the use of adequate tools and know the structure and composition of scientific presentation and discussion, They are able to combine the knowledge and skills acquired in their studies with questions of current research and to use basic knowledge and the acquired methodology. The students are able to present concrete questions in a presentation in English and to propose solutions for a scientific approach as well as to describe the basics of the field in a scientific style in English and - are competent in the independent incorporation, documentation and presentation of topics from physics in English based on current research work using the skills acquired in the course of study.					

	The students know the principles of good scientific practice.
4	**Requirements for Participation** Proof of at least 42 credit points in the Master's degree program in Physics
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, written/oral Examination, Standard)
6	**Requirements on the Award of Credit Points** Passed examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, written/oral Examination Weight: 100%, Standard) Graded subject examination in writing (Project Proposal) and oral presentation of the results (approx. 30 min)
8	**Usability of the Module** MSc Physics, 3rd semester
9	**Literature** is specified by the professor for the specific topic
10	**Comment**

Module Description

Module name **Master Thesis Physics**						
Module no. 05-00-5020	**Credit Points** 27 CP	**Workload** 810 h	**Self-study** 810h	**Duration** 1 Semester	**Frequency** Each. semester	
Language of Instruction Englisch			**Person responsible for the Module** Dean of Studies			
1	**Courses of the Module**					
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**	
2	**Study Content** Familiarisation with and working out a work plan on a topic in physics Experimental and/or theoretical treatment of the topic documentation of the results by writing the Master's thesis					
3	**Learning Outcomes** The students - know the basics of a current, usually research-related, in-depth question, know methods for dealing with the questions at an advanced level and are familiar with adequate tools for dealing with the topic, know the structure and composition of scientific papers and elements of scientific presentation and discussion, - are able to apply the knowledge and skills acquired during their studies to the concrete scientific problem with the newly acquired methods and aids in order to work on the task scientifically in the required breadth and depth, they are able to present the results in an adequate form in writing and orally and to discuss them scientifically in English, and - are competent in the independent research, documentation and presentation of scientific topics from physics in English using the skills acquired in the study programme.					
4	**Requirements for Participation** Successfully completed the module 05-25-5005 " Practical Introduction to Scientific Research”					
5	**Form of Examination**					

	Final Module Examination: • Final examination (Master Thesis Physics, written examination, weighting: 100%, Standard)
6	**Requirements on the Award of Credit Points** Passed written examination (Master Thesis)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, written Examination, Weight: 100%, Standard)
8	**Usability of the Module** MSc Physics, 4th semester
9	**Literature** is specified by the professor for the specific topic
10	**Comment**

Module Description

<table>
<tr><td colspan="7">Module name

Oral Presentation of Master Thesis</td></tr>
<tr><td>Module no.
05-10-5005</td><td>Credit Points
3 CP</td><td>Workload
90 h</td><td>Self-study
90 h</td><td>Duration
1 Semester</td><td colspan="2">Frequency
Each. semester</td></tr>
<tr><td colspan="3">Language of Instruction
Englisch</td><td colspan="4">Person responsible for the Module
Dean of Studies</td></tr>
<tr><td>1</td><td colspan="6">Courses of the Module</td></tr>
<tr><td></td><td>Course no.</td><td colspan="2">Course name</td><td>Workload (CP)</td><td>Form of Teaching</td><td>Contact Hours per Week</td></tr>
<tr><td>2</td><td colspan="6">Study Content
Presentation of the results of the Master Thesis in a oral presentation followed by a scientific discussion.</td></tr>
<tr><td>3</td><td colspan="6">Learning Outcomes
The students
know the structure and composition of scientific papers and elements of scientific presentation and discussion,
are able to present the results orally in English in an adequate form and to lead a scientific discussion,
are competent in the independent preparation and presentation of delimited topics from physics in English using the skills acquired during their studies.</td></tr>
<tr><td>4</td><td colspan="6">Requirements for Participation</td></tr>
<tr><td>5</td><td colspan="6">Form of Examination
Final Module Examination:
• Module Examination (Final Examination, oral Examination, Duration 30 min, Standard)

Presentation approx. 30 min</td></tr>
<tr><td>6</td><td colspan="6">Requirements on the Award of Credit Points
Passed examination</td></tr>
<tr><td>7</td><td colspan="6">Grading
Final Module Examination:
• Module Examination (Final Examination, oral Examination, Weight: 100%, Standard)</td></tr>
</table>

8	**Usability of the Module** Mandatory module in M.Sc. Physics
9	**Literature** is specified by the professor, depending on the field of research.
10	**Comment** 90 hours Preparation and performance of the presentation (partly with guidance)