RUHR
UNIVERSITÄT
BOCHUM

Faculty of Physics and Astronomy

Module Manual

Master of Science (M.Sc.) in Physics

PO 2021 and PO 2023

Ruhr-Universität Bochum

SoSe 2025
03.04.2025

The examination regulations PO 2021 expire on 30 September 2025. You can take a Master's examination in accordance with these study and examination regulations for the last time on 30 September 2025.

The Master of Science in Physics programme has a standard period of study of 4 semesters and a total of 120 credit points (CP). The study programme is divided into different areas. In the first year compulsory elective modules include in-depth modules from experimental and theoretical physics (15-36 CP) as well as diverse modules from the minor subject (5-18 CP). For the specialisation, courses amounting to 15-25 CP must be chosen in one subject area (astronomy/astrophysics, biophysics, solid state physics, nuclear and particle physics or plasma physics). In the area of key competences the obligatory module "project management" has to be chosen and further modules of up to 10 CP can be selected. A list of the approved modules can be found in this module handbook. In the second year compulsory modules amounting to 60 CP cover the subject-specific and interdisciplinary preparation and execution of the final thesis.

The distribution of the 120 CP to be completed in the physics degree programme is illustrated in the following table:

Master of Science	Semester	Experimental physics	Theoretical physics	Focus area	Minor subject	Key qualifications	Master's thesis
		9-18 CP	6-18 CP	15-25 CP	5-18 CP	5-15 CP	60 CP
First year	1	Elective modules experimental physics (astro/bio/solid state/ nuclear and particle/plasma)	Elective modules theoretical physics (thermodynamics and statistical/advanced quantum mechanics/general relativity)	Specialised lecture/seminar/ advanced lab work (astro/bio/solid state/ nuclear and particle/plasma) (oral exam 2 CP)	Physics-related courses of other faculties (e.g. math, engineering, etc.)	e.g. C++ or Scientific Writing	
	2	Elective modules experimental physics (astro/bio/solid state/ nuclear and particle/plasma)	Elective modules theoretical physics (astro/solid state/plasma)		Physics-related courses of other faculties (e.g. math, engineering, etc.)	Project management	
Second year	3						Knowledge of methods and project planning Project seminar for the Master's thesis
	4						Master's thesis

Key

- Experimental physics
- Focus areas
- Key qualifications (choice)
- Master's thesis and prepatory courses
- Theoratical physics
- Minor subject
- Key qualifications (oblig.)

Actually two different examination regulations are in force:

- Students who have enrolled **by the summer semester 2023 at the latest** are in the 2021 examination regulations (PO 2021)
- Students who have enrolled **from the winter semester 2023/2024** are in the examination regulations 2023 (PO 2023)

The two examination regulations differ only minimally. The amended rules are marked in each case.

This overview is structured as follows:

1. counselling and information services
2. study plan
3. modularisation concept and examination forms
4. list of individual compulsory and elective modules

1. Counselling and information services at the Faculty of Physics and Astronomy

If you have any questions in connection with the subject of physics, please contact the student advisory service for physics. They offer appointments five days a week. There are no regular office hours, so you must make an appointment in person, by phone or by e-mail in advance.

Our student advisors for the Master's programme in Physics:

National Students	International Students
General Questions Dr. Ivonne Möller NB 02/169 Fon.: +49(0)234-32-29105 moeller@physik.rub.de	General Questions Dr. Andreas Kreyssig NB 4/130 Fon.: +49(0)234-32-23648 master-international@physik.rub.de
	Admission process Dr. Niklas Fornefeld NB 02/171 Fon.: +49(0)234-32-2 fornefeld@physik.rub.de

Before starting their studies, every student must attend a counselling appointment. In addition to individual appointments, group appointments are also offered. The students are informed about the appointments by e-mail.

General information and forms are provided in the Moodle course "Physics Study Info". After enrolment all students get access to the course.

2. Study plan:

Modul	**Description**	**Semester**	**Exam**
Modul 1.x 9 -18 CP	One (or two) elective module(s) from one of the following subject areas from experimental physics: astrophysics, biophysics, solid state physics, nuclear and particle physics or plasma physics. Each module consists of a lecture with exercise as well as experiments from the advanced practical course from the respective subject area.	1.+2.	graded, the partial performances achieved are weighted with the CP in the module grade. One module from 1a to 1e (of choice) must be completed. A further module can be taken.
Modul 2.x 6 -18 CP	PO 2021: one (or three) module(s) from "Thermodynamics and Statistical Physics", "Advanced Quantum Mechanics" and "General Relativity" PO 2023: "Thermodynamics and Statistical Physics" has to be chosen, if it hasn't been chosen in the Bachelor already. The modules "Advanced Quantum Mechanics" and "General Relativity can be chosen in addition.	1.+2.	Graded, via a module final written exam or an oral examination. PO 2021: one module from 2a to 2c (at choice) must be completed. PO 2023: module from 2c must be completed. Two further modules can be taken. Graded, the partial performances achieved are weighted with the CP in the module grade.
Modul 3.x 0-12 CP	One (or two) elective module(s) from one of the following subject areas from experimental physics: astrophysics, solid state physics or plasma physics. Each module consists of a lecture with exercises.	1.+2.	Graded, the partial performances achieved are weighted with the CP in the module grade. One or two module(s) from 3a to 3c (at choice) can be completed.
Modul 4.x 15-25 CP	One compulsory elective module from one of the following subject areas: Astrophysics, Biophysics, Solid State Physics, Nuclear and Particle Physics or Plasma Physics. Courses from experimental and/or theoretical physics from the respective subject area can be selected	3.+4.	Graded, via a final oral module examination (2 CP). A seminar (2 CP) and practicals (advanced lab work) (min. 5 CP) must be proven.

Modul 5.x 5-18 CP	Elective modules of 5- 18 CP from the catalogue of minor subjects (e.g. mathematics, chemistry, geosciences, ICAMS, neuroscience, engineering science). A complete list of all modules can be found further on in the module handbook.	1.-4.	Graded, via a final module examination, final oral module examination, seminar lecture, study-related exercises and active participation, protocols, practical exercises or homework.
Modul 6.x 0-10 CP	Elective modules in the amount of 0-10 CP from the area of key competences	2.+3.	Graded, via a module final examination, oral module final examination, seminar lecture, study-related exercises and active participation, protocols, practical exercises or term paper.
Modul 7 5 CP	Project Management	1.+2.	ungraded, via active participation
Modul 8 15 CP	Methodology and Project Planning (M.Sc.)	3.	ungraded, via active participation
Modul 9 15 CP	Project seminar for the Master's thesis	3.+4.	graded, via active participation and seminar talk
Modul 10 30 CP	Master thesis	3.+4.	graded, via two expert reports

3. Modularisation concept and forms of examination:

Examinations can take the form of a written examination, an oral examination, a seminar paper, a presentation, a term paper, a written report, a project, a practical exercise or a tutorial. The form of examination for each module can be found in the module descriptions. In the case of alternative options, a form of examination is determined by the lecturer at the beginning of the module.

All modules are completed with an examination. The compulsory modules "Project Management" and "Methodological Knowledge and Project Planning" remain ungraded. All graded modules are weighted with the CP in the final grade.

The "focus module" (compulsory elective modules 4.a to 4.e) concludes with an oral examination, which is credited with 2 CP. The following applies to all courses in the specialisation module:
semester hour per week = CP.

The current range of courses offered by the Faculty of Physics and Astronomy can be found in CampusOffice.

All examinations at the Faculty take place in fixed examination periods. The first examination period is at the end of the lecture period, the second at the end of the lecture free period.

4. List of all modules:

Modules 1 (Elective Modules from Experimental Physics)

Modules 2 (Elective Modules from Theoretical Physics)

Module 3 (Elective Modules from Theoretical Physics)

Modules 4 (Elective Modules for the Focus Area)

Modules 5 (Elective Modules from the Catalogue for Minor Subjects)

Modules 6 (Elective Modules from the Area for Key Competences)

Compulsory Modules

Introduction to Astrophysics					
Module 1a	**Credits** 9 CP	**Workload** 270 h	**Semester** from 1. Sem.	**Cycle** Summer	**Duration** 1-2 Semesters
Courses a) Lecture Introduction to Astrophysics b) Exercises for Introduction to Astrophysics c) Advanced Laboratory Courses for Physicists (three experiments in Astrophysics/Astronomy)			**Contact Hours** a) 44 h b) 22 h c) 21 h	**Self-Study** 183 h	**Group Size** a) unlimited b) 30 c) 2

Requirements for Participation
Formal None
Content Basic knowledge of Physics I-III (Bachelor) are highly appreciated
Preparation None

Learning Outcomes
After successfully completing this module, the students
- know the central concepts, theories and research fields of modern multi-wavelength and multi-messenger astrophysics.
- are able to apply the different metrological and modelling methods of astrophysics to simple examples.
- analyse and evaluate relevant scientific contents and communicate them in a differentiated manner, both orally and written.
- know and motivate the significance of physics and astronomy for society and the importance of internationally cooperative research.

Contents
Methods and results of astrophysics are introduced using selected observational phenomena and presented in connection with the results from current research. The topics taught include, among others: Basics of observational cosmology, structure formation in the cosmos, active galactic nuclei, dark matter, radiation processes, radiation transport, gravitational lensing, stellar dynamics, state variables of stars, solar neutrinos, phases of the interstellar medium, accretion disk physics, pulsars. In the advanced laboratory course, basic scientific computing and programming skills are acquired on the basis of concrete problems.

Format of Teaching Lecture, Exercises, Practical Exercises (Laboratory Course)

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The advanced laboratory course is examined via practical exercises and protocols.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course. In addition, the advanced laboratory course must be successfully completed. Both grades go into the module grade with the CP-weighted.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to credit points

Module Supervisor and Instructor Prof. Dr. Bomans

Further Information

Introduction to Biophysics

Module 1b	Credits	Workload	Semester	Cycle	Duration
	9 CP	270 h	from 1. Sem.	Winter	1-2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Biophysics b) Exercises for Introduction to Biophysics c) Advanced Laboratory Courses for Physicists (three experiments in Biophysics)	a) 44 h b) 22 h c) 21 h	183 h	a) unlimited b) 30 c) 2

Requirements for Participation
Formal None
Content Basic knowledge in Physics I-III (Bachelor) will be highly appreciated
Preparation None

Learning Outcomes
After successfully completing this module, the students
- have a basic understanding of molecular structures of living matter
- can realise the relation between the basic knowledge from experimental and theoretical physics and the examination of biological systems, and they can use them to describe equilibriums and reactions
- are familiar with the basic physical methods for examining molecular biological processes
- are able to plan, execute, evaluate and record in writing biophysical experiments and to discuss the results in the scientific context
- have received a first glance at current research topics of molecular biophysics at Ruhr-University Bochum
- can acquire relevant scientific contents, theories, and methods, both guided and independent, and they can communicate their results both orally and written

Contents
- Structure of biological Matter: from the atom to the protein
- Spectroscopical methods
- Methods for determining structures of proteins (X-ray crystallography, NMR, electron microscopy)
- Fundamentals of reaction kinetics and electrochemistry

Format of Teaching Lecture, Exercises, Practical Exercises (Laboratory Course)

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The advanced laboratory course is examined via practical exercises and protocols.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course. In addition, the advanced laboratory course must be successfully completed. Both grades go into the module grade with the CP-weighted.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to credit points

Module Supervisor and Instructor Prof. Dr. Gerwert, Prof. Dr. Hofmann

Further Information

Introduction to Solid State Physics

Module 1c	Credits	Workload	Semester	Cycle	Duration
	9 CP	270 h	from 1. Sem.	Winter	1-2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Solid State Physics b) Exercises for Introduction to Solid State Physics c) Advanced Laboratory Courses for Physicists (three experiments in Solid State Physics)	a) 44 h b) 22 h c) 21 h	183 h	a) unlimited b) 30 c) 2

Requirements for Participation
Formal None
Content Basic knowledge in Physics I-III (Bachelor) will be highly appreciated
Preparation None

Learning Outcomes
After successfully completing this module, the students

- Have a basic understanding on how quantum mechanical and classical processes influence macroscopic and microscopic characteristics of solid state matter
- Are aware of the possibilities of the general concepts to derive the optical, thermal and electronic properties of solid state matter from the basic methods of physics and to achieve at least a qualitive understanding of those concepts
- Know the fundamental concepts of applying quantum mechanics to solid state systems
- Are aware of scattering phenomena in the position and momentum space
- Can see and apply relations between atomic and solid state physics with regards to electronic, phononic and photonic band structure.

Contents
- Geometric structure of solid state matter
- (ideal crystals, misorder, reciprocal lattice, determining crystalline structure via diffraction, bonding phenomena)
- Dynamics of the crystalline lattice
- (lattice oscillations, phonons, Bose-Einstein-distribution, thermal properties of non-conductors, scattering experiments)
- Electrons in solid state matter
- (Classical free electron gas, Fermi-Dirac-Distribution, electric conductivity, thermal properties of conductors, metallic bonding, charges in magnetic fields, band model, experimental determination of band gaps, semi-conductors, thermal excitation of charges, effective mass, conducting by holes and faults, pn-junction

Format of Teaching Lecture, Exercises, Practical Exercises (Laboratory Course)

Format of examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The advanced laboratory course is examined via practical exercises and protocols.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course. In addition, the advanced laboratory course must be successfully completed. Both grades go into the module grade with the CP-weighted.
Use of the Module Compulsory-Elective Module
Importance of the Mark for the Final Grade Weighted according to credit points
Module Supervisor and Instructor Prof. Dr. Böhmer
Further Information

Introduction to Nuclear and Particle Physics

Module 1d	Credits 9 CP	Workload 270 h	Semester from 1. Sem.	Cycle Winter	Duration 1-2 Semesters

Courses	**Contact Hours**	**Self-Study**	**Group Size**
a) Lecture Introduction to Nuclear and Particle Physics b) Exercises for Introduction to Nuclear and Particle Physics c) Advanced Laboratory Courses for Physicists (three experiments in Nuclear and Particle Physics)	a) 44 h b) 22 h c) 21 h	183 h	a) unlimited b) 30 c) 2

Requirements for Participation
Formal None
Content Knowledge of Physics I-III (Bachelor) will be expected
Preparation None

Learning Outcomes
After successfully completing this module, the students

- have a basic understanding of the structure of matter and its interactions as well as radioactivity
- are aware of the possible applications of nuclear physical processes in technology and medicine
- know the fundamental concepts of electromagnetic, weak, and strong interaction
- are familiar with general measurement techniques and methods and can evaluate advantages and disadvantages of nuclear physical and radioactive processes
- see correlations between processes in the universe and in nuclear and particle physics
- can evaluate the place into context the results of nuclear physical and radioactive processes

Contents
Nuclear physics processes in the universe, structure of matter from elementary particles - the standard model of particle physics, structure and description of atomic nuclei, relativistic heavy ion physics, interaction of ponds with matter and detectors based on them, introduction to quantum field theory, processes of the strong and electroweak interaction, scattering and decay experiments, particle accelerators, applications of nuclear and particle physics in technology and medicine, radioactivity and radiation exposure, evaluation of experiments.

Format of Teaching Lecture, Exercises, Practical Exercises (Laboratory Course)

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The advanced laboratory course is examined via practical exercises and protocols.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course. In addition, the advanced laboratory course must be successfully completed. Both grades go into the module grade with the CP-weighted.

Use of the Module Compulsory-Elective Module
Importance of the Mark for the Final Grade Weighted according to credit points
Module Supervisor and Instructor Prof. Dr. Wiedner
Further Information

Introduction to Plasma Physics

Modul 1e	Credits	Workload	Semester	Cycle	Duration
	9 CP	270 h	from 1. Sem.	Summer	1-2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Plasma Physics b) Exercises for Introduction to Plasma Physics c) Advanced Laboratory Courses for Physicists (three experiments in Plasma Physics)	a) 44 h b) 22 h c) 21 h	183 h	a) unlimited b) 30 c) 2

Requirements for Participation
Formal None
Content Knowledge of Physics I-III (Bachelor) will be appreciated
Preparation None

Learning Outcomes
After successfully completing this module, the students

- Have a basic understanding of the important characteristics of a plasma and of the forms of describing of plasma in the single particle model, and of the kinetic and fluid description
- Are aware of the applications of low and high temperature plasma and their locking concepts
- Know the fundamental concepts of plasma equilibrium
- Are familiar with the dynamics of plasma
- Can see correlations between plasma heating and plasma properties and can apply physical measurement techniques to known problems

Contents
Basic concepts and plasma definition, single particles in magnetic fields, collision interactions, hydrodynamics, magnetohydrodynamics, kinetic theory, boundary layers, waves in plasmas, basics of controlled fusion, special forms of discharge

Format of Teaching Lecture, Exercises, Practical Exercises (Laboratory Course)

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The advanced laboratory course is examined via practical exercises and protocols.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course. In addition, the advanced laboratory course must be successfully completed. Both grades go into the module grade with the CP-weighted.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Golda

Further Information

General Relativity

Modul 2a	**Credits** 6 CP	**Workload** 180 h	**Semester** from 1. Sem.	**Cycle** Winter	**Duration** 1 Semester
Courses a) Lecture General Relativity b) Exercises for General Relativity			**Contact Hours** a) 44 h b) 22 h	**Self-Study** 114 h	**Group Size** a) unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully completing this module, the students

- Have a basic understanding of gravity as curvature of space-time
- Are aware of the possibilities of differential-geometric methods
- Know the fundamental concepts of gravity and their applications
- Can see connections between physical ideas and can apply their mathematic form

Contents

- Special relativity and flat spacetime: Lorentz transformations; vectors and dual vectors (1-forms); tensors; Maxwell equations; energy-momentum tensor; classical field theory.
- Manifolds: Gravity as a geometric property; What is a manifold; Vectors, tensors, metrics; An expanding universe; Causality; Tensor densities; Differential forms; Integration
- Curvature: covariant derivative; parallel transport and geodesics; the Riemann curvature tensor; symmetries and Killing vectors; maximally symmetric spaces; geodesic divergence
- Gravitation: physics in curved spacetime; Einstein equations; Lagrangian formulation; the cosmological constant; alternative theories
- The Schwarzschild solution: the Schwarzschild metric; Birkhoff's theorem; singularities; geodesics of the Schwarzschild solution; black holes; the maximally extended Schwarzschild solution
- Cosmology: Maximally symmetric universe; Robertson-Walker metric; the Friedmann equation; scale factor dynamics; redshift and distances; Gravitational lensing; inflation

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min or oral examination of 30 min) for the module.

Requirements for the Attribution of Credit Points Passing the examination

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Grauer

Further Information

Advanced Quantum Mechanics

Modul 2b	Credits 6 CP	Workload 180 h	Semester from 1. Sem.	Cycle Winter	Duration 1 Semester
Courses a) Lecture Advanced Quantum Mechanics b) Exercises for Advanced Quantum Mechanics			**Contact Hours** a) 44 h b) 22 h	**Self-Study** 114 h	**Group Size** a) unlimited b) 30

Requirements for Participation
Formal None
Content Knowledge of the contents of "Introduction to Quantum Mechanics and Statistics" (Bachelor) will be expected
Preparation None

Learning Outcomes
After successfully completing this module, the students
- Have an understanding of advanced concepts of quantum mechanics, enabling them to analyse complex physical phenomena
- Can see and apply fundamental correlations between symmetries in quantum mechanics and its underlying mathematical form of group theory
- Have an overview of the most important approximative methods of quantum mechanics and can apply them independently to non-relativistic phenomena
- Are familiar with scattering theory and the quantum mechanical treatment of identical particles
- Gained basic knowledge of relativistic field equations and their quantification

Contents
Symmetries in quantum mechanics, addition of angular momentum, selection rules, approximation methods and their applications, scattering theory, systems of identical particles, field quantisation, relativistic wave equations

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 180 min or oral examination of 45 min) for the module.

Requirements for the Attribution of Credit Points Passing the examination

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Epelbaum

Further Information

Statistical Physics (until SoSe 2023) **Thermodynamics and Statistical Physics (from SoSe 2024)**					
Modul 2c	**Credits** 6 CP	**Workload** 180 h	**Semester** from 1. Sem.	**Cycle** Summer	**Duration** 1 Semester
Courses a) Lecture Thermodynamics and Statistical Physics b) Exercises for Thermodynamics and Statistical Physics			**Contact Hours** a) 44 h b) 22 h	**Self-Study** 114 h	**Group Size** a) unlimited b) 30

Requirements for Participation
Formal None
Content Knowledge of the contents of "Introduction to Quantum Mechanics and Statistics" (Bachelor) will be expected
Preparation None

Learning Outcomes
After successfully completing this module, the students
- Have a basic understanding of the concepts of statistical mechanics
- Know the fundamental concepts of quantum statistics
- Are familiar with fundamental definitions of classical and quantum mechanical statistical physics
- Can solve typical problems of non-interacting multi-particle physics

Contents
Quantum statistics and classical statistical mechanics, thermodynamics, applications. Starting point is the simple statistics of many particles, thermodynamics is derived from this. Afterwards quantum statistics with applications

Format of Teaching Lecture, Exercises

Format of Examination Written examination of 120 min

Requirements for the Attribution of Credit Points Passing the examination

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Eremin

Further Information The module "Statistical Physics" is equivalent to the module "Thermodynamics and Statistical Physics".

Introduction to Theoretical Astrophysics

Modul 3a	Credits	Workload	Semester	Cycle	Dauer
	6 CP	180 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Theoretical Astrophysics b) Exercises for Introduction to Theoretical Astrophysics	a) 44 h b) 22 h	114 h	a) unlimited b) 30

Requirements for Participation
Formal None
Content Basic knowledge of theoretical physics (Bachelor level) is highly appreciated
Preparation None

Learning Outcomes
After successfully completing this module, the students

- Have a basic understanding of theoretical astrophysics
- Are aware of the possibilities of the used mathematisation and modelling
- Know the fundamental concepts for describing astrophysical environments
- Are familiar with different theoretical methods
- Can see and successfully apply correlations between astrophysics, respective examples and different branches of physics (nuclear and particle physics, plasma physics)

Contents
Methods and results of astrophysics are introduced for selected astrophysical systems and discussed in connection with current research results. Focal points are selected from the following topics: Astrophysics: definition and fundamentals (the latter are provided in short digressions as required); Stars: state variables, formation, structure, evolution and final states; Stellar winds: acceleration, structure and interaction with the interstellar medium; Stellar atmospheres: Structure and radiative transfer; Stellar winds: acceleration, structure and interaction with the interstellar medium; Milky Way, galaxies: structure; Cosmic rays: acceleration and transport.

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture.

Requirements for the Attribution of Credit Points Depending on the defined form of examination: Passing the written/oral examination or obtaining at least 50 % of the possible points in the weekly exercises. In this case, active participation in the exercises is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor PD Dr. Fichtner

Further Information

Introduction to Theoretical Solid State Physics

Modul 3b	Credits	Workload	Semester	Cycle	Duration
	6 CP	180 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Theoretical Solid State Physics b) Exercises for Introduction to Theoretical Solid State Physics	a) 44 h b) 22 h	114 h	a) unlimited b) 30

Requirements for Participation
Formal None
Content Knowledge of theoretical physics, including the contents of "Introduction to Quantum Mechanics and Statistics" (Bachelor), will be expected
Preparation None

Learning Outcomes
After successfully completing the module, the students
- Know the fundamental concepts of solid state theory
- Have a basic understanding of the microscopic properties with regards to structure, the properties of oscillation, and the electronic properties and their influence on the macroscopic behaviour of the solid state
- Are familiar with the mathematical representation of solid states (second quantification, sudden breaking of symmetry, phase transition, elementary excitation)
- Can solve and interpret typical exercises of solid state theory

Contents
- Geometric structure of the solid
- (ideal crystals, disorder, reciprocal lattice, crystal structure determination by diffraction, bonding ratios)
- Dynamics of the crystal lattice
- (lattice vibrations, phonons, Bose-Einstein distribution, thermal properties of the non-conductor, scattering experiments)
- Electrons in the solid state
- (classical free electron gas, Fermi-Dirac distribution, electrical conductivity, thermal properties of conductors, metallic bonding, charge carriers in the magnetic field, band model, experimental determination of band gaps, semiconductors, thermal excitation of charge carriers, scattering experiments)
- excitation of charge carriers, effective mass, hole conduction, impurity conduction, pn junction)

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Dr. Lechermann

Further Information

Introduction to Theoretical Plasma Physics

Modul 3c	Credits	Workload	Semester	Cycle	Duration
	6 CP	180 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Theoretical Plasma Physics b) Exercises for Introduction to Theoretical Plasma Physics	a) 44 h b) 22 h	114 h	a) unlimited b) 30

Requirements for Participation
Formal None
Content Basic knowledge of theoretical physics, especially electrodynamics (Bachelor level), is highly appreciated
Preparation None

Learning Outcomes
After successfully completing the module, the students

- have gained a basic understanding of the problems of theoretical model building for a complex many-particle system.
- are familiar with the descriptions of plasmas on the basis of kinetic and fluid dynamic theories and are able to assess the possibilities and limitations of such models
- know the basic mathematical techniques for working within the framework of the theories developed in the module
- are familiar with respective plasma-physical applications of the theories and methods in the context of astrophysics and space physics and have an insight into the parameter regimes found there
- have gained initial experience in the numerical modelling of plasma-physical processes in the context of the practical experiments and have carried out corresponding computer simulations.

Contents
Basic concepts of classical plasma physics, single particle motion, kinetic theory, fluid theory, magnetohydrodynamics, equilibrium theory, waves and instabilities, applications in astro- and space-physical context, numerical modelling of plasmas

Format of Teaching Lecture, Exercises, numerical computer simulation

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Tjus

Further Information

<table>
<tr><td colspan="6">Astrophysics/Astronomy</td></tr>
<tr><td>Modul 4a</td><td>Credits
15-25 CP</td><td>Workload
450-750 h</td><td>Semester
1.-2. Sem.</td><td>Cycle
Winter & Summer</td><td>Duration
2 Semesters</td></tr>
<tr><td colspan="3">Courses
a) Lecture
b) Exercises
c) Seminar (at least 2 CP)
d) Advanced Laboratory Courses
(at least 5 CP)
A complete overview of the courses can be found in the current course catalogue. The CP of the individual courses result from the semester hours per week (1 hour per semester week = 1 CP)</td><td>Contact Hours
Each at least.
a) 44 h
b) 44 h
c) 22 h
d) 35 h</td><td>Self-Study
min. 309 h</td><td>Group Size
a) unlimited
b) 30
c) 30
d) 2</td></tr>
<tr><td colspan="6">Requirements for Participation
Formal None
Content Basic knowledge of astronomy/astrophysics will be expected
Preparation None</td></tr>
<tr><td colspan="6">Learning Outcomes
After successfully completing the module, the students
have learned to apply physical knowledge from different fields (such as plasma and quantum physics) to the often 'exotic' conditions of space compared to Earth.
Have gained a basic understanding of the most important physical processes describing the different phenomena in the universe
know the basic theoretical concepts of modern astronomy and astrophysics
are informed about current astrophysical issues
are able to read, understand and classify astrophysical literature
are able to write their Master's thesis in the field of experimental or theoretical astronomy / astrophysics</td></tr>
<tr><td colspan="6">Contents
Modern astrophysical topics are introduced. In the process, the students are taken to the 'front line of research'. This is done with special emphasis on the research foci of the participating chairs and working groups in experimental and theoretical astrophysics/astronomy, but a broad overview is also provided. Extragalactic astronomy, up to (observational) cosmology and astroparticle physics, takes up a large amount of space. Interactions of different components (such as phases of the interstellar medium, galactic disk / halo or galaxies / intergalactic medium) are of particular importance. But also processes in our own Milky Way are presented in detail. Here, the focus is on the gas and dust components of the Milky Way and the formation of stars and - linked to this - planetary systems, but also on solar-terrestrial relationships, such as the physics of the solar wind. Close relations exist with plasma physics and nuclear and particle physics.</td></tr>
<tr><td colspan="6">Format of Teaching Lecture, Exercises, Seminar, Laboratory Work</td></tr>
<tr><td colspan="6">Format of Examination Oral examination of 45 minutes</td></tr>
<tr><td colspan="6">Requirements for the Attribution of Credit Points Passing the oral examination.
The specialisation module must include: advanced laboratory courses (5 CP) and a seminar (2 CP). Including the final oral module examination (2 CP), 15-25 CP can be achieved.</td></tr>
</table>

Achievements made after the final module examination no longer count towards the module.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighed according to Credit Points

Module Supervisor Prof. Dr. Bomans

Examiners Prof. Dr. Bomans, Prof. Dr. Franckowiak, Prof. Dr. Hildebrandt, Prof. Dr. Riseley, Prof. Dr. Tjus, PD Dr. Fichtner

Further Information For advice and coordination of the courses, please contact the module supervisor.

Course	Type	No.	Semester
Advanced Laboratory Course for Physicists	Laboratory	160250	Winter
			Summer
Advanced Laboratory: Observational Astronomy	Laboratory	160624	Winter
			Summer
Astroparticle Physics	Lecture	160614	Summer
	Exercises	160615	
Astrophysical Fluids, Plasmas and Shocks	Lecture	160623	Winter
Chaos, Turbulence and Stochastic Systems	Lecture	160532	Summer
	Exercises	160533	
Cosmology	Lecture	160611	Winter
	Exercises	160612	
Crossing the Desert	Seminar	160665	Winter
		160661	Summer not in 25
Fluid Dynamics in Astrophysics	Lecture	160615	Winter
		160605	Summer not in 25
Galaxy Clusters	Lecture	160618	Summer
Gamma-ray Astronomy	Seminar	160667	Summer
Interstellar Medium Astrophysics	Lecture	160601	Summer
Introduction to Space Physics	Lecture	160618	Winter
	Exercises	160619	
Introduction to Statistics for Astronomers and Physicists	Lecture	160613	Summer
Methods in Theoretical Astroparticle Physics	Seminar	160610	Winter
		160623	Summer not in 25
Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II	Lecture	160511	Summer
	Exercises	160512	
Modelling Transport and Interactions of Cosmic Rays	Lecture	160616	Summer not in 25
	Exercises	160617	
Multi-Wavelength Astrophysics	Seminar	160666	Winter
		160662	Summer
Observational Cosmology	Seminar	160661	Winter
		160650	Summer
Radio Astronomy	Lecture	160613	Winter
Research Topics in Heliophysics	Seminar	160663	Winter
Selected Topics of Astronomy	Seminar	160621	Winter
Selected Topics of Astronomy II	Seminar	160620	Summer

Stars, Winds, Nebulae	Lecture	160608	Winter
The Milky Way and External Galaxies	Lecture	160602	Winter
Theoretical Heliophysics	Seminar	160609	Winter
	Seminar	160624	Summer not in 25
Theoretical Neutrino Astrophysics	Lecture	160616	Winter
	Exercises	160617	
Variabilities and Instabilities in Stars	Lecture	160660	Summer
X-ray Astronomy	Lecture	160610	Summer

Cosmology

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Cosmology	a) 33 h	76 h	a) Unlimited
b) Exercises for Cosmology	b) 11 h		b) 30

Requirements for Participation
Formal None
Content Introduction to Astrophysics
Preparation Prior successful participation in an astronomy introductory lecture

Learning Outcomes
After successful completion of the module, students

- have an understanding of the properties of a homogeneous, isotropic universe
- are aware of the physics of the thermal history of the universe
- know the physical concepts of cosmic structure formation and the cosmic microwave background
- are familiar with the basics of the inflationary universe, re-ionisation, gravitational lensing and galaxy evolution
- are ready to work on a master thesis with a cosmological topic

Contents
The lecture starts with a description of the physics of homogeneous, isotropic universes, a.k.a. Friedmann-Lemaitre-Robertson-Walker universes. Their contents, past and future evolution, and observational avenues to constrain such models are discussed. Starting from the hot big bang, the thermal history of the universe is covered, connecting insights from particle physics, thermodynamics, and the above mentioned homogeneous, isotropic world models. Next, structure formation and evolution are discussed, starting from tiny primordial fluctuations all the way to the structures we see in the universe today. The cosmic microwave background (CMB) is introduced and understood based on these concepts. Cosmic inflation, re-ionisation, gravitational lensing and galaxy evolution are covered, always with a focus on connecting theoretical cosmology with observations.

Format of Teaching Lecture, Exercises

Format of Examination Oral exam

Requirements for the Attribution of Credit Points Active participation in the exercises and successful completion of the oral exam

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Hildebrandt

Further Information

Crossing the Desert

	Credits	Workload	Semester	Cycle	Duration
	2 CP	90 h	from 1. Sem.	Winter & Summer (not in 25)	1 Semester
Courses			**Contact Hours**	**Self-Study**	**Group Size**
a) Seminar Crossing the Desert			a) 22 h	68 h	a) Unlimited

Requirements for Participation
Formal None
Content Knowledge from "Introduction to Nuclear and Particle Physics" as well as "Astroparticle Physics"
Preparation None

Learning Outcomes
After successful completion of the module
- students are able to work on topics from astroparticle physics independently
- students are able to receive and understand specialist articles by scientists from the international research landscape
- students are able to lead a technical discussion on topics of particle physics beyond the Standard Model

Contents
The seminar deals with sub-areas of research in the field of neutrino and gamma astronomy and related fields such as cosmology and particle physics. Methods of analysing the large amounts of data generated in this field can also be covered.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation and presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Rhode

Further information Block event in the week of 17 February 2025, purely digital for Bochum and Dortmund, Course offered by TU Dortmund with RUB participation

Introduction to Space Physics

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Space Physics b) Exercises for Introduction to Space Physics	a) 22 h b) 11 h	57 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content Basic knowledge of Theoretical Physics
Preparation None

Learning Outcomes
After successful completion of the module

- students have a basic understanding of Space Physics
- students are aware of the capabilities of the corresponding mathematization and of the modelling
- students know the basic concepts for the quantitative description of space physical processes and systems and can apply them successfully
- students are able to recognize connections between space physics and astrophysics and plasma physics

Contents
Methods and results of space physics will be presented for selected space physical systems and will be discussed in the context of current research. Focus areas will be selected from the following topics: the Sun, the quiet and disturbed solar wind and its interaction with the terrestrial environment (magnetosphere as well as the interstellar medium (heliosphere), waves and turbulence in the solar wind, transport of energetic particles, space weather

Format of Teaching Lectures and exercises

Format of Examination At the beginning of the course the docent defines the type of exam (e.g., written exam of 45 min duration, oral exam of 30 min duration, or several shorter (multiple choice) tests during the lecture period).

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral exam or obtaining at least 50% of the possible points in the weekly exercise tasks. In this case, active participation in the exercise is also mandatory. The form of examination will be determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor PD Dr. Fichtner

Further information

Modelling Transport and Interactions of Cosmic Rays

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group size
a) Lecture Modelling Transport and Interactions of Cosmic Rays b) Exercises for Modelling Transport and Interactions of Cosmic Rays	a) 22 h b) 11 h	57 h	a) 20 b) 20

Requirements for Participation
Formal None
Content Knowledge in one or more of the following programming languages Python, C++, and Fortran is useful and recommended.
Preparation None

Learning Outcomes
During this course, the students will:

- get familiar with different methods to model the transport and interaction of cosmic rays
- understand advantages and disadvantages of different modelling concepts based on the physics problems
- develop experience to set up and run various software tools to model CR transport
- learn to transfer simulation outputs into physical quantities
- gain basic knowledge to optimize the simulation models based on measurements of CR observables

Contents

- Ultrahigh-energy cosmic rays: Single particle propagation and efficient nuclei-photon interaction modelling
- Galactic cosmic rays: Complex magnetic field models (coherent + turbulent), ensemble averaged transport (grid based and stochastic differential equations), nuclei-nuclei interaction
- Source physics: Non-linear time evolution of energy spectra, tabulated interaction rates, matrix methods
- From simulation to physics values: Re-weighting, normalization, comparison with observables

Format of Teaching Lecture, Exercises

Format of Examination The lecturer defines the kind of examination (90 min written exam, 45 min oral exam or weekly homework including active participation) at the beginning of the course.

Requirements for the Attribution of Credit Points Depending on the kind of examination: Passing the written/oral exam or reaching at least 50 % of the possible points in the (bi-)weekly homework assignments. In the latter case, active participation in the exercise group is mandatory, too. The form of examination will be defined at the beginning of the course.

Use of the Module Elective Module

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Merten, Prof. Dr. Tjus

Further Information

Multi-Wavelength Astrophysics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Multi-Wavelength Astrophysics	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal Work on a bachelor / master thesis in the multi-wavelength astronomy group
Content Lecture “Basics of Astronomy”, „Astroparticle Physics“ is recommended
Preparation Final exam of the module astronomy (master)

Learning Outcomes
After successful completion of the module students
- have a broad overview of state-of-the-art topics in multi-messenger astrophysics
- know how to present their work to an international group of experts
- learn to participate in the discussion among international experts
- have acquired the skillset to complete their bachelor / master theses

Contents
This weekly seminar brings together the members of the multi-wavelength astrophysics group. It covers topics of neutrino astronomy, gamma-ray astronomy, optical astronomy and numerical modelling of multi-wavelength data. We discuss recent papers concerning the topic and members of the group regularly present their work. The students get first insights into the inner workings of large collaborations, have opportunities to interact with international colleagues and present their work to the group.

Formats of Teaching Seminar

Format of Examination Regular active participation in the form of short presentations of the students‘ work, discussions with the group members and subsequent follow-up.

Requirements for the Attribution of Credit Points
At this stage, i.e. after the start of the bachelor/master thesis, students typically do not require additional credit points. However, points can still be awarded if necessary for regular active participation as detailed above.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Franckowiak

Further information

Observational Cosmology

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Observational Cosmology	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal Work on a bachelor/master thesis in the observational cosmology group
Content Lecture “Cosmology” and preferably also “Astrostatistics” (master); lecture “Basics of Astronomy” (bachelor)
Preparation Final exam of the module astronomy (master)

Learning Outcomes
After successful completion of the module students
- have a good understanding of the work in a research group;
- are familiar with the interactions in an international research team;
- have learned to present their work to their peers in a regular setting;
- can conduct scientific discussions, respond to questions and criticism, and take on professional advice for their work;
- have acquired the skillset to complete their bachelor/master theses.

Contents
This weekly meeting brings together all members of the observational cosmology group to discuss progress, problems, and current topics. It is expected that students present their weekly progress to the team, get input from their peers, and improve their work through new ideas, productive criticism, and discussions. The work of the group members in several international research teams is discussed giving the students first insights into the inner workings of such collaborations, potentially with opportunities to interact with international colleagues and present their work to a wider audience.

Format of Teaching Seminar

Format of Examination Regular active participation in the form of short presentations of the students’ work, discussions with members of the group, and subsequent follow-up.

Requirements for the Attribution of Credit Points
At this stage, i.e. after the start of the bachelor/master thesis, students typically do not require additional credit points. However, points can still be awarded if necessary for regular active participation as detailed above.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Hildebrandt

Further information

Radio Astronomy

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Radio Astronomy	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Introduction to Astrophysics and a good understanding of Fourier Transforms

Learning Outcomes
After successful completion of the module

- students have a basic understanding of radio astronomical imaging techniques
- Students are aware of the capabilities of modern radio telescopes and receivers
- students know the basic concepts of emission and absorption mechanisms of astronomical bodies radiating in the radio regime
- are familiar with radio astronomical polarisation measurements
- students are able to recognize connections between plasma physics, high energy particle physics and radio astronomy
- students are able to perform their Master Thesis within the area of radio astronomy

Contents
The first half of the lecture will introduce students to the technical part of radio astronomy such as receiver and correlator technology and explain the mathematical principles needed for generating interferometric radio images. Data calibration methods will be illustrated and imaging algorithms introduced as well as methods to analyse radio interferometric data products.
The second half of the lecture gives an overview of the astronomical science radio astronomy is mostly associated with such as magnetic fields, star-formation, active supermassive galactic nuclei and time domain radio astronomy.

Format of Teaching Lecture

Format of Examination Oral exam 45 min

Requirements for the Attribution of Credit Points Passing the oral exam

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Adebahr

Further information

Research Topics in Heliophysics					
	Credits 2 CP	**Workload** 60 h	**Semester** from 1. Sem.	**Cycle** Winter	**Duration** 1 Semester
Courses a) Seminar Research Topics in Heliophysics			**Contact Hours** a) 22 h	**Self-Study** 38 h	**Group Size** a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successful completion of the module

- students will have an overview of the research topics currently being investigated in the heliophysics group
- students will have presented their own ongoing work (resulting in a B.Sc., M.Sc., or Ph.D. thesis) to the other group members
- students will have learned to make an oral presentation of their current work to a specialized audience
- students are able to summarize, to comprehensively present, and to critically discuss the motivation, methodology and results of their work

Contents
In a series of talks by B.Sc., M.Sc., or PhD: students they present the motivations, methods and results of their thesis-related work on helio- and astrophysical topics. Thereby focused scientific discussions are triggered that help the presenter to improve her/his work and give the specialized audience an overview over other heliophysical and related astrophysical topics.

Format of Teaching Seminar

Format of Examination Oral presentation

Requirements for the Attribution of Credit Points Oral presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor PD Dr. Fichtner

Further information

Selected Topics of Astronomy

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Selected Topics of Astronomy	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal Yes
Content Yes
Preparation Solid knowledge of the foundations of Astronomy is needed, as presented in the lecture „Grundlagen der Astronomie“ and attendance of the lecture „Introduction to Astrophysics“ highly recommended. Previous attendance of more specialized Astronomy/Astrophysics lecture is recommended, but not required.

Learning Outcomes
The seminar is intended to give the students exposure to cutting edge Astronomical/Astrophysical science topics, train the understanding of research papers, the presentation of science results at the knowledge level of their fellow students, and discuss them following each of the presentations. (This requires the participation in at least most of the seminar dates.)

Contents
In the seminar the students select from a list of topical papers the one to present. The topics are selected by the full-time lecturers and therefore reflect mostly the work topics actively pursued at the Astronomical Institute. With help of the respective advisors the students prepare the topics to be presented in their seminar talk and are provided with help for the actual presentation. Result of presenting one talk, plus listening and discussing the other talks of the seminar will provide a view of some topical research in Astronomy/Astrophysics.

Format of Teaching Seminar

Format of Examination Oral presentation and activity in the discussions after the talk

Requirements for the Attribution of Credit Points Successful presentation of the seminar talk and active participation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisors and Instructors Prof. Dr. Bomans, Prof. Dr. Dettmar, Prof. Dr. Franckowiak, Prof. Dr. Hildebrandt

Further information

Stars, Wind, Nebulae

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Stars, Wind Nebulae	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Basic knowledge in astronomy (e.g. Introduction to Astronomy course) necessary

Learning Outcomes
Students will get a broader view on the stellar evolution and consequences of mass loss. Mainly from an observational perspective but also theoretical concepts are introduced and discussed.

Contents
The course concentrates on stellar evolution of stars of all masses. A focus is given on the parameters that influence the evolution – in particular the stellar mass loss and its consequences. The lecture addresses the topic from an observational point of view but also theoretical models presented. Beside the observational characteristics also the mechanism of stellar winds are addressed. The formation of circumstellar nebula from stellar winds and possible shell ejections is another topic of the lecture. In this context the lecture briefly tackles several concepts and properties of the Interstellar medium.

Format of Teaching Lecture

Format of Examination Possible are an oral exam, a short oral presentation or written essay

Requirements for the Attribution of Credit Points Active participation and a successful examination

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor PD Dr. Weis

Further information

The Milky Way and External Galaxies

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture The Milky Way and External Galaxies	a) 33 h	57 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Solid knowledge of the foundations of Astronomy is necessary, as it is presented in the lecture „Grundlagen der Astronomie“. Previous attendance of the lecture „Introduction to Astrophysics“ is helpful, but not required.

Learning Outcomes
After the successful completion of the course students will have gained a deeper understanding of structure, kinematics, and evolution of our Milky Way galaxy. Using these concepts, in the second part of the lecture the properties and evolution of external galaxies will explored and a coherent picture for evolution of galaxies inside the evolving universe will be derived.

Contents
The course consists of the two major parts: the exploration of the physical properties of our Milky Galaxy and the extension to the various types of external galaxies, both the underlining goal to derive a consistent picture for the evolution of galaxies from the early universe to today. Methods and results for the structure, kinematics, star formation history, and chemical evolution will be presented and applied to the different galaxy types and conclusions for the evolution of the galaxy types derived.

Format of Teaching Lecture

Format of Examination Usually a short oral presentation, alternatively (if special conditions apply) a written essay or an oral exam

Requirements for the Attribution of Credit Points Active participation and a successful examination

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Bomans

Further information

Theoretical Heliophysics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Theoretical Heliophysics	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successful completion of the module

- students will have a basic insight into selected topics of contemporary heliophysical research
- students will have familiarized themselves with one topic in more detail on the basis of one or more research publication(s)
- students will have learned to make an oral presentation of a chosen scientific problem to an interested audience
- students are able to extract, to summarize, and to critically discuss the essence of a given research paper

Contents
In a series of student presentations methods and results of various heliophysical and related astro-physical studies are critically discussed. Thereby an introduction into theoretical heliophysics is pro-vided on the basis of topics that are in the focus of current research activities. Besides the scientific content it is also conveyed how a scientific presentation should be structured and made.

Format of Teaching Seminar

Format of Examination The oral presentation (or, in exceptional cases, the term paper) will be evaluated

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral exam or obtaining at least 50% of the possible points in the weekly exercise tasks. In this case, active participation in the exercise is also mandatory. The form of examination will be determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted aver-age final grade

Module Supervisor and Instructor PD Dr. Fichtner, Dr. Kleimann

Further information

Biophysics					
Modul 4b	**Credits** 15-25 CP	**Workload** 450-750 h	**Semester** 1.-2. Sem.	**Cycle** Winter & Summer	**Duration** 2 Semesters
Courses a) Lecture b) Exercises c) Seminar (at least 2 CP) d) Advanced Laboratory Courses (at least 5 CP) A complete overview of the courses can be found in the current course catalogue. The CP of the individual courses result from the semester hours per week (1 hour per semester week = 1 CP).			**Contact Hours** Each at least. a) 44 h b) 44 h c) 22 h d) 35 h	**Self-Study** min. 309 h	**Group Size** a) unlimited b) 30 c) 30 d) 2

Requirements for Participation
Formal none
Content Knowledge from "Introduction to Biophysics" will be expected
Preparation none

Learning Outcomes
After successfully completing the module, the students

- re familiar with the molecular biological processes as well as the physical methods of investigation and can use these to describe equilibria and reactions
- have a deeper insight into current research topics in molecular biophysics at the Ruhr-University Bochum
- are able to work out scientific contents, theories and methods independently and to communicate them confidently orally and in writing
- can independently find and use information in the relevant databases
- are proficient in analysing data on protein sequence and structure with suitable programmes.

Contents
Structural resolution methods, X-ray crystallography, energy refinement, modelling,
Force fields, molecular dynamics simulation, QM/MM simulation, FTIR and Raman scattering, spectroscopy applied to current problems, bioinformatics.

Format of Teaching Lecture, Exercises, Seminar, Laboratory Work

Format of Examination Oral examination of 45 minutes

Requirements for the Attribution of Credit Points Passing the oral examination.
The specialisation module must include: advanced laboratory courses (5 CP), a seminar (2 CP). Including the final oral module examination (2 CP), 15-25 CP can be achieved. Achievements made after the final module examination no longer count towards the module.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor Prof. Dr. Gerwert, Prof. Dr. Hofmann

Examiners Prof. Dr. Gerwert, Prof. Dr. Hofmann, Prof. Dr. Mosig, PD Dr. Kötting

Further Information For advice and coordination of the courses, please contact the module supervisor. Please see the course list below.

Course	Type	No.	Semester
Advanced Laboratory Course for Physics Students	Laboratory	160250	Winter Summer
Basics and Current Topics of Protein Crystallography	Literature Seminar	160835	Winter
Bioinformatics	Seminar	160857	Summer
Biophotonics	Literature Seminar	160830	Winter
Biophysics	Seminar	160820	Summer
Biophysics II	Lecture	160801	Summer
	Exercises	160802	
Colloquium Biophysics	Colloquium	160853	Summer
Computer Simulation of Proteins	Seminar	160852	Summer
FTIR in Biophysics	Seminar	160858	Summer
Laboratory Biophysics: Molecular Biology of Proteins for Physics Students	Laboratory	160821	Winter
Laboratory Biophysics: Selected Topics of Molecular Biophysics for Physics Students	Laboratory	160823	Winter
Literature Seminar: Basics and Current Topics of Proteincrystallography	Seminar	160856	Summer
Methods and Applications in Structural Bioinformatics	Seminar	160854	Summer
Proteincrystallography	Seminar	160855	Summer
Research Laboratory: Selected Topics of Molecular Biophysics	Laboratory	160859	Summer

Methods and Application in Structural Bioinformatics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer	1 Semester

Course	Contact Hour	Self-Study	Group Size
a) Seminar Methods and Application in Structural Bioinformatics	a) 22 h	38 h	a) unlimited

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes:
After successful completion of the module, students will have

- gained an overview of current methodological developments and their applications in the field of theoretical biophysics and structural bioinformatics.
- a basic understanding of how to critically evaluate and present literature.
- acquired the basic concepts for a good literature presentation.

Contents
During the seminar, literature on current applications and methodological developments in the field of theoretical biophysics and structural bioinformatics will be presented and discussed.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the seminar events (>75%) and an own literature presentation.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Rudack / Prof. Dr. Hofmann

Further Information

Solid State Physics

Modul 4c	Credits	Workload	Semester	Cycle	Duration
	15-25 CP	450-750 h	1.-2. Sem.	Winter & Summer	2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture b) Exercises c) Seminar (at least 2 CP) d) Advanced Laboratory Courses (at least 5 CP) A complete overview of the courses can be found in the current course catalogue. The CP of the individual courses result from the semester hours per week (1 hour per semester week = 1 CP).	Each at least. a) 44 h b) 44 h c) 22 h d) 35 h	min. 309 h	a) unlimited b) 30 c) 30 d) 2

Requirements for Participation
Formal none
Content Basic knowledge of solid state physics will be expected
Preparation none

Learning Outcomes
After successfully completing the module, the students

- have a basic understanding of the properties of the solid state, its atomic structure, and its electrical, magnetic, mechanical and optical properties
- are aware of the possibilities within the different research areas and specialisations of theoretical and experimental solid state physics
- know the basic concepts of the theoretical description of the solid state
- are familiar with basic experimental procedures for measuring solid state properties
- re able to recognise correlations between the microscopic structure of the solid body and its macroscopic properties and apply these to estimate technological usability

Contents
Deepening of knowledge in the main areas of solid state physics, especially optical, magnetic and superconducting properties. Theoretical solid state physics deals with the many-body problem and places the main areas of solid state physics on a solid quantum mechanical basis. In addition, a number of special lectures are offered for in-depth study: Surface Physics, Magnetism, Superconductivity, Semiconductor Physics and Semiconductor Devices, Phase Transitions, Metal Physics, Scattering Physics, Physics of Thin Films, Nanostructuring and Spintronics, and other areas in modern experimental and theoretical solid state physics.

Format of Teaching Lecture, Exercises, Seminar, Laboratory Work

Format of Examination Oral examination of 45 minutes

Requirements for the Attribution of Credit Points Passing the oral examination.
The specialisation module must include: advanced laboratory courses (5 CP), a seminar (2 CP). Including the final oral module examination (2 CP), 15-25 CP can be achieved. Achievements made after the final module examination no longer count towards the module.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor Prof. Dr. Hägele			
Examiners Prof. Dr. Böhmer, Prof. Dr. Botti, Prof. Dr. Drautz, Prof. Dr. Eremin, Prof. Dr. Hägele, Prof. Dr. Liebscher, Prof. Dr. Scherer, Prof. Dr. Sulpizi, Prof. Dr. Wieck			
Further Information For advice and coordination of the courses, please contact the module supervisor. Please see the course list below.			
Course	**Type**	**No.**	**Semester**
Advanced Laboratory Course for Physics Students	Laboratory	160250	Winter
			Summer
Advanced Electron Microscopy NEW	Lecture	160334	Summer
	Exercises	160335	
Advanced Physics of 2-Dimensional Materials NEW	Lecture	160337	Summer
Advanced Solid State Theory	Lecture	160311	Summer
	Exercises	160312	
Advanced Techniques in Transmission Electron Microscopy NEW	Seminar	160336	Summer
CODEFI Seminar NEW	Seminar	440524	Summer
Compact Course: Practical Exercises in Semiconductor Technology	Compact Laboratory	160305	Winter
Computer Simulations in Statistical Physics	Lecture	160332	Summer
	Exercises	160333	
Journal Club: Applied Solid State Physics	Seminar	160324	Winter
		160322	Summer not in 25
Introduction to Solid State Physics II	Lecture	160303	Summer
	Exercises	160304	
Introduction to Statistics for Astronomers and Physicists	Lecture	160613	Summer
Introduction to X-Ray and Neutron Scattering	Lecture	160315	Summer
Quantum Materials	Seminar	160350	Winter
	Lecture	160317	Summer
	Exercises	160318	
Quantum Optics	Lecture	160328	Summer
	Exercises	160329	not in 25
Physics of Complex Phase Transitions in Solids	Lecture	160319	Summer
	Exercises	160320	not in 25
Physics of Quantum Cascade Lasers	Lecture	160311	Winter
	Seminar/ Exercises	160312	
Physical Principles of Electron Microscopy	Lecture	160313	Winter
Physical Principles of Quantum Information	Lecture	160330	Summer
	Exercises	160331	
Scientific Methods of Semiconductor Physics	Lecture	160301	Winter
	Exercises	160302	
	Lecture	160306	Summer
	Exercises	160307	
Selected Topics of Applied Solid State Physics	Seminar	160322	Winter
		160353	Summer
Selected Topics of Solid State Physics Theory	Seminar	160327	Winter
		160354	Summer
Semiconductor Band Structures	Seminar/ Lecture	160351	Winter

	Seminar	160321	Summer
Semiconductor Physics I	Lecture	160303	Winter
	Exercises	160304	
Semiconductor Physics II: Experiments with Semiconductor Quantum Devices	Lecture	160309	Summer
	Exercises	160310	
Seminar on Quantum Materials	Seminar	160326	Summer (not in 25)
Solid State Physics Theory	Seminar	160325	Winter
Solid State Theory	Seminar	160323	Summer
Spintronics and Ultrafast Spectroscopy	Seminar	160323	Winter
		160358	Summer
Superconductivity	Seminar	160327	Summer
Surface Physics and Chemistry	Lecture	160510	Summer
Theory of Electronic Excitations in Materials NEW	Lecture	440523	Summer

Advanced Electron Microscopy

	Credits	Workload	Semester	Cycle	Duration
	8 CP	120 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture “Advanced Electron Microscopy” b) Exercise “Advanced Electron Microscopy”	a) 33 h b) 11 h	a) 57 h b) 19 h	a) Unlimited b) Unlimited

Requirements for Participation
Formal None
Content Basic knowledge of optics, solid state physics and quantum mechanics
Preparation None

Learning Outcomes
After successful completion of the module

- students know the basic working principles of electron microscopes and crystallography with a focus on transmission electron microscopy
- students understand the basics of electron wave propagation in solids
- students gain knowledge in aberration-corrected electron optics
- students learn to differentiate between high resolution transmission electron microscopy and scanning transmission electron microscopy
- students understand how to interpret and simulate atomic resolution images
- students are familiar with differential phase contrast imaging and electronic ptychography
- students obtain knowledge in advanced electron tomography and spectroscopy

Contents
The course starts with explaining the working principles of electron microscopes with a focus on transmission electron microscopy. The basic principles of crystal lattices and electron diffraction will be explained. Students will learn to describe the electron wave propagation and related approximations in crystalline materials. The concepts of aberration-correction electron optics will be discussed before explaining the mechanism of atomic resolution imaging by high resolution transmission electron microscopy and scanning transmission electron microscopy. With this knowledge, students will learn how to interpret atomic resolution images and use computer simulations to gain quantitative insights in the atomic structure of solid state materials. The students will gain first insights into advanced interferometric imaging methods such as electron ptychography to image the atomic structure of weak scattering objects (light elements). Electron tomography will be introduced and students will learn how to obtain three-dimensional information from samples down to the atomic level. The students will obtain knowledge in atomic level X-ray and electron energy loss spectroscopy and understand the principle concept of vibrational spectroscopy in the electron microscope. In the exercises, the use of computer-based simulation and analysis tools will be introduced. Students will learn how to simulate and analyse complex multidimensional datasets.

Format of Teaching Lecture, Exercise

Format of Examination The students give a talk of 45 min, plus discussion within the lecture group.

Requirements for the Attribution of Credit Points Active participation (>75%) and successful presentation with valid discussion.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Liebscher

Further information

Advanced Physics of 2D Materials

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture "Advanced Physics of 2D Materials"	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content Basic knowledge of solid state physics is highly appreciated
Preparation Participation in the module "Introduction to Solid State Physics" is useful

Learning Outcomes
After successful completion of the module, students have a basic understanding of

- two-dimensional materials
- Moiré pattern
- Magic angle bi-layer graphene
- Superconductivity in graphene
- Magnetism in two-dimensional materials
- Experimental techniques such as synthesis of 2D materials, exfoliation techniques
- Potential applications of 2D materials

Contents
In recent years two-dimensional van der Waals materials are at the forefront of research in condensed matter physics and material science. On the one hand, the magic angle bi-layer graphene has set a new trend in unconventional superconductivity. On the other hand, the presence of long-range magnetic order in two-dimensional van der Waals materials has completely opened a new avenue for the investigation of magnetism in true 2D-systems. This lecture will cover the most recent advancements in the field of 2D-materials starting from the magic angle bi-layer graphene (MABLG), Moiré pattern, emerging magnetic van der Waals materials and their potential for applications. The experimental techniques used to synthesize these 2D-materials together with the exfoliation techniques.

Format of Teaching Lecture, Seminar, Exercise

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min or oral examination of 45 min)

Requirements for the Attribution of Credit Points Depending on the specified form of examination: The form of examination will be determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Böhmer

Further information

Advanced Solid State Theory

	Credits	Workload	Semester	Cycle	Duration
	8 CP	240 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Advanced Solid State Theory b) Exercises for Advanced Solid State Theory c) Seminar Advanced Solid State Theory	a) 44 h b) 22 h c) 22 h	152 h	a) Unlimited b) 25 c) 25

Requirements for Participation
Formal None
Content Basic knowledge of solid state theory, statistical mechanics and quantum mechanics is desirable
Preparation None

Learning Outcomes
After successful completion of the module

- students have a basic understanding of the modern methods of the theoretical solid state physics including quantum field theory methods and many-body theory
- Students are able to derive an effective Hamiltonian of the given solid state systems using second quantization and to compute elementary excitations and thermodynamic observables
- students know the basic concepts of functional integral description of the thermodynamic phase transitions in solid state systems
- students are familiar with Feynman diagrams at zero and finite temperatures and can use this formalism for various model systems
- students are able to employ simple numerical algorithms to obtain the thermodynamic properties of the quantum mechanical systems using Monte-Carlo or similar techniques

Contents

- Green's Functions(Interaction representation, Green's Functions: Many particle Green's functions); Zero Temperature Feynman Diagrams, Feynman rules in momentum space, the self-energy, response functions, the RPA (Large-N) electron gas;
- Finite Temperature Many Body Physics , Imaginary Time Green Functions, Generating Function and Wick's theorem, Examples of the application of the Matsubara Technique,
- Fluctuation Dissipation Theorem and Linear Response Theory, Electron transport Theory, The Kubo Formula,
- Phase Transitions and broken symmetry, Ginzburg Landau theory, Thermal Fluctuations and criticality,
- Coherent states and path integrals, Effective action and Hubbard Stratonovich transformation,
- Superconductivity and BCS theory, Local Moments and the Kondo effect.

Format of Teaching Lecture, Exercises, Seminar

Format of Examination At the beginning of the course, the lecturer determines the form of the examination. (written exam of 90 min, oral exam of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture. The seminar is examined via a presentation by the student on the selected topic, related to the modern research

Requirements for the Attribution of Credit Points Depending on the defined form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also mandatory. The form of examination will be determined at the beginning of the course. In addition, the F practical course must be completed successfully. Both grades go into the module grade with the CP weighted
Use of the Module Courses in Physics Major
Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade
Module Supervisor and Instructor Prof. Dr. Scherer
Further information

Advanced Techniques in Transmission Electron Microscopy

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar "Advanced Techniques in Transmission Electron Microscopy"	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content Basic knowledge in electron microscopy, ideally acquired by attending the lectures "Physical Principles of Electron Microscopy" and/or "Advanced Electron Microscopy", but not required.
Preparation None

Learning Outcomes
The seminar will cover recent developments in electron microscopy, discussing new technique developments and their applications. The students will learn how to understand and summarize research papers, critically reflect on their content and present the work. They will engage in active discussions of the presented content with experts, which requires participation in most of the seminars.

Contents
The seminar will be platform to discuss recent developments in electron microscopy. Either techniques, that are being developed at the Institute of Solid State Physics are discussed, or selected topics (e.g. momentum resolved, high energy resolution or ultrafast microscopy) are being prepared by the students. The students will be assisted by expert advisors on how to perform literature research, to prepare the content for a presentation and how to present content to an audience. The active engagement in the seminar series by following other presentations and discussions will provide the students with a broad overview in current technique development in electron microscopy and equip them with presentation and discussion skills.

Format of Teaching Seminar

Format of Examination The students give a talk of 30 min plus discussion within the seminar group.

Requirements for the Attribution of Credit Points Active participation (>75%) and successful presentation with valid discussion.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Liebscher

Further information

Compact Course: Practical Exercises in Semiconductor Technology

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 week (plus preparation and a presentation of the results

Courses	Contact Hours	Self-Study	Group Size
b) Compact Course: Practical Exercises in Semiconductor Technology	b) 40 h	80 h	a) 3-5

Requirements for Participation
Formal Preparation of content
Content Will be provided
Preparation Participation in module "Special Problems in Applied Solid State Physics" is recommended. Preparation of the content will be checked in advance.

Learning Outcomes
After successful completion of the module

- students have a basic understanding of how semiconductor devices are made from semiconductor chips. And how these functions are tested.
- Students are aware of the capabilities of photo-lithography, device testing setups, focused ion implantation.
- students know the basic concepts of semiconductor devices
- are familiar with photo lithography

Contents
In the practical course, students independently produce a simple field-effect transistor. Basic techniques of semiconductor processing, such as photolithography and wet chemical etching, are learned. Furthermore, students will use focused ion implantation to modify the electrical properties of semiconductor heterostructures. The electrical characterization of the fabricated devices is another focus of the lab. Here, modern, electrical measurement techniques are used for device characterization. Each practical day is introduced with a lecture of about 45 minutes, in which the basics for the work of the day are explained.

Format of Teaching Lab course and lecture

Format of Examination Oral exam about content and plan how to measure the device (midterm during the week). Presentation after the practical.

Requirements for the Attribution of Credit Points Successful oral exam and presentation.

Use of the Module Advanced lab course block in Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Ludwig

Further information

Computer Simulations in Statistical Physics

	Credits	**Workload**	**Semester**	**Cycle**	**Duration**
	6 CP	180 h	from 1. Sem.	Summer	1 Semester

Courses	**Contact Hours**	**Self-Study**	**Group Size**
a) Lecture Computer Simulations in Statistical Physics b) Exercises for Computer Simulations in Statistical Physics	a) 44 h b) 22 h	114 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content None (Recommended: Basic concepts of classical and statistical mechanics)
Preparation None

Learning outcomes
After successfully passing the exam:

- the students will have an understanding of the algorithms used to perform state-of-the-art molecular dynamics and Monte Carlo simulations in Statistical Physics
- they will be able to make computer programs to perform and analyse those simulations
- they will have the knowledge to use and understand available program packages from the literature to perform the simulations

Contents

- Short introduction to basic concepts of thermodynamics, statistical mechanics and introduction to error analysis
- Classical molecular dynamics (MD): integration algorithms, accuracy, thermostats and barostats, Ewald summation
- Monte Carlo and kinetic Monte Carlo: importance sampling, canonical ensemble, master equation
- Grand-canonical simulations and free energy methods
- Quantum mechanical approaches and density functional theory
- Hands-on examples: MD simulations of the Lennard-Jones fluid, MD simulations of the biomolecules, Ising model

Format of Teaching Lecture, Exercises

Format of Examination Oral exam 30 min

Requirements for the Attribution of Credit Points Successful oral exam

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Sulpizi / Dr. Settanni

Further information Language English

Journal Club: Applied Solid State Physics

	Credits	Workload	Semester	Cycle	Duration
	1 CP	30 h	from 1. Sem.	Winter & Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Journal Club: Applied Solid State Physics	a) 11 h	19 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Read articles and participation in module "Special Problems in Applied Solid State Physics" is recommended."

Learning Outcomes
After successful completion of the module

- students have a basic understanding of how to read and understand a scientific article, simplify its content and present it in a compact and concise way.
- Students are aware of the capabilities to access journal articles behind a paywall from the university bibliographic system
- students know the basic concepts of scientific presentation of content, ask basic and scientific questions
- are familiar with literature research methods

Contents
In this journal club we gather weekly to discuss recent relevant research published in scientific journals. One participant of the club presents a summary of the chosen paper that the whole group has read. Then, the content is discussed. Attendees ask clarifying questions, discuss different aspects of the experimental design, critique the methods, judge the writing style, and bring a healthy amount of scepticism (or praise) to the results.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation and presentation of a paper.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Ludwig

Further information

Quantum Materials (Seminar)

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Quantum Materials	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Participation in the module "Introduction to Solid State Physics" is recommended

Learning Outcomes
After successful completion of the module

- students have a basic understanding of the solid-state physics of quantum materials
- students can independently familiarize themselves with an advanced topic in the field of solid state physics of quantum materials
- students have gained experience in literature research
- students are familiar with creating and giving scientific presentations

Contents
Quantum materials are materials whose properties are decisively determined by quantum mechanics. As a part of condensed matter physics, this seminar will provide insight into some of the most famous quantum materials such as heavy fermion systems, high-temperature superconductors and topological materials. In addition to these important concepts of condensed matter physics, we will also get to know a range of experimental techniques that were used to find out about them. Thus, we will get insight into the process of understanding a new material in condensed matter physics and the critical analysis of experimental results and their interpretations.

Format of Teaching Seminar

Format of Examination Presentation, evaluated according to the criteria below

Requirements for the Attribution of Credit Points The criteria for evaluating the seminar presentation are the quality of the thematic introduction, the quality of the presentation slides, the quality of the presentation and the answers to questions about the presentation.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Böhmer

Further information

Physics of Complex Phase Transitions in Solids

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Physics of Complex Phase Transitions in Solids b) Exercise Physics of Complex Phase Transitions in Solids	a) 30 h b) 30 h	60 h	a) 20 b) 20

Requirements for Participation
Formal None
Content None
Preparation Basic knowledge of quantum mechanics / solid state physics and thermodynamics / statistical physics is recommended

Learning Outcomes
After successful completion of the module
- students possess a conceptional understanding of complex phase transitions in solid state materials (e.g. superconducting and ferroic phases)
- students are familiar with state of the art analytical and numerical scale-bridging modelling methods in this field
- students can judge, compare and utilize these concepts and methods
- students can identify the underlying physical properties

Contents
- Introduction to complex phase transitions in solid state materials (e.g. magnetic, ferro-electric and superconducting phases)
- Classification of phase transitions and critical phenomena
- Models and simulation methods (e.g. spin models, Landau theory)

Format of Teaching Lecture, Exercises

Format of Examination Presentation of project work and short oral examination related to the project

Requirements for the Attribution of Credit Points Taking part in the exercises, successful oral presentation of the project

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Eremin, Dr. Grünebohm

Further information Lecture notes will be provided.

Physics of Quantum Cascade Lasers

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Physics of Quantum Cascade Lasers b) Discussion Physics of Quantum Cascade Lasers	a) 22 h b) 11 h	57 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Prior knowledge of quantum mechanics is highly recommended

Learning Outcomes
After successful completion of the module

- Students have a basic understanding of the physics necessary for lasing
- Students are aware of the capabilities and applications of quantum cascade lasers
- Students know the basic concepts of solid-state physics, optical and laser physics that are necessary for the design of quantum cascade lasers.
- Students are familiar with different quantum cascade laser designs

Contents
This course will cover the physics necessary to understand quantum cascade lasers. Quantum cascade lasers are a new class of semiconductor lasers that are based on intersubband transitions. They emit radiation at mid-infrared and far-infrared wavelengths. This contrasts with conventional diode semiconductor lasers which are based on interband transitions and emit radiation at visible and near-infrared wavelengths. The active region of a quantum cascade laser consists of repeating series (cascades) of quantum wells and barriers that are grown in Molecular Beam Epitaxy (MBE) or Metal Organic Vapor Deposition (MOCVD) machines. To achieve lasing, wavefunctions and levels should be designed to maximize/(minimize) the lifetime of the upper/(lower) laser level, reduce parasitic scattering, maximize injection into the upper laser level, and minimize losses. This requires a thorough understanding of the optical properties of two-dimensional semiconductors, and electron transport and scattering in semiconductor heterostructures. In addition to these topics, the course will review basic laser theory and survey different types of waveguides.

Outline

Basic Laser theory: spontaneous emission, stimulated emission, absorption, Einstein A and B coefficients, Rate equations, 3 and 4 level laser systems, laser threshold, gain clamping / saturation, homogeneous and inhomogeneous broadening, multi-mode and single mode lasers, spatial hole burning, longitudinal and transverse modes, spontaneous emission noise and laser line width, frequency pulling, Q-switching, mode-locking line width, different types of lasers.
Wave functions and effective mass: Review of tight binding model, nearly free-electron model, and the formation of bands. Bloch's theorem, envelope approximation, effective mass approximation, hetero-structure effective mass theory - modifications of the continuity conditions and the kinetic operator in the envelope approximation
Idealized potentials parabolic well, infinite square well, finite square well, finite hetero-structure square well, superlattices and minibands, Bloch oscillations, coupled quantum wells, Stark effect
Refinements of effective mass theory: k dot p method, Kane 2 and 3 band models, non-parabolicity
Optical properties of quantum wells: Interband and intraband transitions, absorption in quantum wells, selection rules, oscillator strength – sum rules, depolarization shift, gain and loss, modification of sum rules and transition dipole moments from non-parabolicity
QCL design strategies: two-dimensional rate equations, slope efficiency, importance of lifetimes, parasitic scattering, Bragg confinement, resonant tunneling (qualitative treatment), backfilling and

self-heating, bound-to-continuum designs, LO-phonon designs, chirped supper-lattice and phase space designs **Resonant tunneling injection and extraction**: coupled quantum wells, resonant tunneling diodes, density matrix - two and three-level models, coherent and incoherent transport regimes, scattering assisted injection, electric field domains **Carrier scattering:** phonon scattering, electron-electron scattering, impurity scattering, interface roughness, elevated electron temperatures **Waveguides/mode confinement**: TE and TM modes, dielectric slab waveguides, surface plasmon waveguides, photonic crystals, distributed brag reflectors, mode coupling, orthogonality/completeness of modes, mode overlap factor
Format of Teaching Lecture and exercise/discussion session
Format of Examination Weekly exercises will be assigned. Students are expected to write notes on the lecture material. The grade for the course will be based on a final examination.
Requirements for the Attribution of Credit Points Active participation during the weekly lecture and exercise session is required. Students are required to submit weekly exercises and handwritten lecture notes to Module. The final examination will be written and take approximately 90 minutes to complete. A single grade will be given for both the lecture and exercises.
Use of the Module Courses in Physics Major
Importance of the Mark for the Final Grade The grade will be determined by the final examination.
Module Supervisor and Instructor Dr. Jukam (email: Nathan.Jukam@rub.de)
Further information

Physical Principles of Electron Microscopy

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Physical Principles of Electron Microscopy	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content Basic knowledge of optics, solid state physics and quantum mechanics
Preparation None

Learning Outcomes
After successful completion of the module
- students understand the basic elements of electron microscopes
- gain knowledge in electron optics
- are familiar with electron-specimen interactions
- students understand electron scattering and diffraction theory
- can connect the theory of image formation with image contrast interpretation
- obtain first insights into spectroscopic techniques

Contents
Students will learn to describe the basic elements of electron microscopes (electron guns, electromagnetic lenses, electron detectors) and are able to understand the particle and wave nature of electron optics. The course will explain the fundamental mechanisms of electron specimen interactions with a focus on elastic and inelastic scattering. Details of image formation mechanisms related to scattering and phase contrast will be described to be able to interpret image contrast formation. The basic theory of electron scattering and diffraction will be explained and will be demonstrated by experimental examples. The course will provide first insights into spectroscopic techniques and how they can be used to analyse the composition and electronic structure of solid state materials.

Format of Teaching Lecture

Format of Examination The students give a talk of 45 min. plus discussion within the lecture group

Requirements for the Attribution of Credit Points Active participation (>75%) and successful presentation with valid discussion.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Liebscher

Further information

Physical Principles of Quantum Information

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Physical Principles of Quantum Information b) Exercises for Physical Principles of Quantum Information	a) 22 h b) 22 h	76 h	a) Unlimited b) Unlimited

Requirements for Participation
Formal None
Content Knowledge of linear algebra, quantum mechanics
Preparation None

Learning Outcomes
Understanding of the physical principles of quantum information and quantum engineering with quantum superconducting circuits

Contents
In the first part of the course the basic principles of quantum information, i.e., quantum logic and algorithms, quantum computing, adiabatic quantum computing, quantum games, quantum machine learning, quantum simulations, etc., will be addressed. The second part of the course will be devoted to a particular realization of quantum information devices, i.e., super-conducting qubits circuits.

Recommended literature:
- M. A. Nielsen, I. Chuang, “Quantum computation and quantum information”
- D. Heiss, “Fundamentals of quantum information: quantum computation, communication, decoherence and all that”
- M. Kjaergaard et al. “Superconducting qubits: Current state of play”

Format of Teaching Lecture, Exercises

Format of Examination Oral exam 30 min

Requirements for the Attribution of Credit Points Successful oral exam

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Fistul

Further information Lectures and exercises will be in English

Scientific Methods of Semiconductor Physics

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Scientific Methods of Semiconductor Physics b) Exercises for Scientific Methods of Semiconductor Physics	a) 22 h b) 11 h	57 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successful completion of the module

- students have a basic understanding of preparation, work principles and analytics of semiconductor devices
- Students are aware of the capabilities of semiconductors in transport and optics
- students know the basic concepts of thermodynamics concerning evaporation rates, electric charge carrier densities and excitations in solids
- are familiar with electron and hole dynamics in semiconductors
- students are able to recognize connections between the materials and bandgaps, doping, mobility and electrical conductivity and apply this knowledge to all semiconductors

Contents
Material composition of semiconductors from the periodic table, bandgaps, pn-junction, Shockley-equation, bipolar transistor, historical point-contact Schottky-transistor, field-effect transistor, current-voltage (IV) measurements, temperature dependence of the electric carrier density, simple basic circuits with diodes and transistors, negative and positive feedback, operational amplifiers, linearization of non-linear active devices, noise, oscilloscope, spectrum analyser, lock-in amplifier, typical and popular semiconductor devices with hints for their applications in laboratory life, checking of individual or connected devices, typical failures in electronics, electrolytic capacitors and their problems, sustainability aspects and planned obsolescence including strategies how to react, repair strategies of electronic equipment

Format of Teaching Lecture, Exercises

Format of Examination In the last part of the semester, each student performs a talk of 45 min. about a self-defined subject in the vicinity of the lecture's contents in front of the whole auditorium and the professor. If this is not possible for administrative reasons (e.g. not enough dates available), an individual oral examination of 45 min. will be performed

Requirements for the Attribution of Credit Points Successful talk / examination

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Wieck

Further information

Selected Topics of Applied Solid State Physics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Selected Topics of Applied Solid State Physics	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation None or "Participation in solid state physics module is recommended."

Learning Outcomes
After successful completion of the module

- students have a basic understanding of applied solid state physics
- Students are aware of the capabilities of semiconductors in transport and optics
- students know the basic concepts of molecular beam epitaxy and focused ion beam technology
- are familiar with experimental techniques of actual semiconductor research
- students are able to recognize connections between semiconductor materials and their applications

Contents
Talks and discussions on actual topics of applied solid state research. In particular, molecular beam epitaxy and focused ion beam technology including the preparation of semiconductor devices and technical aspects of the applied instruments/machines. An important issue is the creation of ultra-high vacuum for most of the preparative techniques. Frequently discussed subjects are quantum devices like single photon sources, quantum dots and low-dimensional electrical carrier systems in general.

Format of Teaching Lecture, talks, discussions

Format of Examination The student performs a talk of 45 min. plus discussion within the research group

Requirements for the Attribution of Credit Points Successful talk with valid discussion

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Ludwig, Prof. Dr. Wieck

Further information

Semiconductor Band Structures

	Credits	Workload	Semester	Cycle	Duration
	1 CP	30 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Semiconductor Band Structures	a) 11 h	19 h	a) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Participation in module "Special Problems in Applied Solid State Physics" is recommended.

Learning Outcomes
After successful completion of the module

- students have a basic understanding of semiconductor band structure calculations
- Students are aware of the capabilities of software packages to perform complex device simulations
- students know the basic concepts of heterostructure devices
- are familiar with creating device concepts based on band structure and functionalities

Contents
The ability to create semiconductor heterostructures by combining different constituents from the periodic table of elements in perfect crystalline arrangements is a huge technological leap. It enabled the creation of highly efficient and miniaturized optoelectronic devices like laser light sources and ultrafast electronic components. Key to this is the control of the arrangement of the crystal matrix elements and dopants resulting in the band structure, the spatial arrangement of the electrostatic potential and (quantized) energy states of carriers. In the seminar we will calculate the quantized states and the band structure of different devices like quantum wells, high electron mobility transistor and diode structures. The structures developed in practical exercises will be in close relation to structures used for quantum experiments with e.g. qubit, single photon source, and single electron source Leviton devices.

Format of Teaching Seminar, practicals

Format of Examination Active participation and presentation of an own simulation project

Requirements for the Attribution of Credit Points Active participation and presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Ludwig

Further information

Semiconductor Physics I

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Semiconductor Physics I b) Exercises for Semiconductor Physics I	a) 33 h b) 11 h	76 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successful completion of the module
- students have a basic understanding of crystals, doping, electronic transport, band structures and optics in semiconductors
- Students are aware of the capabilities of different models applied to describe semiconductor physics
- students know the basic concepts of selected semiconductor devices
- students are familiar with semiconductors

Contents
Crystals, band structures, doping, electronic transport and optics in semiconductors are covered to achieve a basic understanding in these concepts. Models to describe and methods to produce semiconductors are introduced. The physics and operation principles of selected semiconductor devices are presented.

Format of Teaching Lecture, Exercise

Format of Examination Oral examination at the end of the lecture

Requirements for the Attribution of Credit Points Active participation in the training class and pass the oral exam

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Dr. Ludwig

Further information

Solid State Physics Theory

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Solid State Physics Theory	a) 22 h	38 h	a) 25

Requirements for Participation
Formal None
Content Basic knowledge of solid state theory, statistical mechanics and quantum mechanics is desirable
Preparation None

Learning Outcomes
After successful completion of the module

- students have developed a basic understanding of the modern topics of the solid state theory
- Students are able to work independently with the modern literature on theoretical and experimental solid state physics and make scientific presentations on a given topic
- students know the basic concepts of solid state theory and can use them to understand and to comprehend new scientific articles

Contents
Brief description of the subject content:

- topological band theory and its application to the novel quantum materials
- basics of the quantum information and qubits realization
- concepts of Phase Transitions and broken symmetry
- Coherent states and path integrals,
- Superconductivity and BCS theory

Format of Teaching Seminar

Format of Examination The seminar is examined via a presentation by the student on the selected topic, related to the modern research.

Requirements for the Attribution of Credit Points Depending on the defined form of examination: Passing the written/oral examination or obtaining at least 50 % of the possible points in the weekly exercises. In this case, active participation in the exercise is also mandatory. The form of examination will be determined at the beginning of the course. In addition, the F practical course must be completed successfully. Both grades go into the module grade with the CP weighted.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Eremin

Further information

Spintronics and Ultrafast Spectroscopy

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Spintronics and Ultrafast Spectroscopy	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal Lecture Physik IIIa/b
Content None
Preparation Physik IIIa/b

Learning Outcomes
After successful completion of the module

- students have a basic understanding of basic concepts of time-resolved spectroscopy, non-linear optics, higher order coherence in stochastic measurement outcomes, and spintronic devices.

Contents
Time-resolved pump-probe spectroscopy with 100 fs – temporal resolution. Non-linear optics. Spin noise spectroscopy. Second order frequency resolved spectra. Higher order polyspectra and their measurement. Quantum Polyspectra. Optical spin injection. Spin-transport.

Format of Teaching Seminar talks by students and instructors

Format of Examination The student prepares and delivers a talk at the seminar (35-45 Minutes) and is prepared for a subsequent discussion.

Requirements for the Attribution of Credit Points Successful examination. Attendance of the seminar and oral contributions to discussions.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Hägele

Further information

Nuclear and Particle Physics

Modul 4d	Credits	Workload	Semester	Cycle	Duration
	15-25 CP	450-750 h	1.-2. Sem.	Winter & Summer	2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture b) Exercises c) Seminar (at least 2 CP) d) Advanced Laboratory Courses (at least 5 CP) A complete overview of the courses can be found in the current course catalogue. The CP of the individual courses result from the semester hours per week (1 hour per semester week = 1 CP).	Each at least. a) 44 h b) 44 h c) 22 h d) 35 h	min. 309 h	a) unlimited b) 30 c) 30 d) 2

Requirements for Participation
Formal None
Content Knowledge from “Introduction to Nuclear and Particle Physics” will be expected
Preparation None

Learning Outcomes
After successfully completing the module, the students

- understand both how the Standard Model of particle physics was developed and its predictive power
- can make the connection between quantum field theory predictions and experiments
- have a deeper understanding of the electromagnetic, weak and strong interactions
- are familiar with and can interpret Nobel Prize experiments in nuclear and particle physics
- are able to make the connection between symmetries and experimental observations
- possess a knowledge of open questions and current research topics in the field of nuclear and particle physics
- can explain the connection between particle physics and the development of the universe

Contents
Dirac equation, spin, antiparticles, conservation laws, Feynman diagrams, Yukawa interaction, strangeness, group theory and symmetry, Clebsch-Gordon coefficients, meson nonets, Breit-Wigner resonances, colours in QCD, charm, confinement, Global and local symmetries, hadron structure, parton model, deep inelastic scattering and scale behaviour, neutrino physics, weak WW, mixing states, Higgs mechanism of mass production, physics beyond the Standard Model, quantum field theories, solitons. In addition, special events are offered in the form of lectures and seminars on detectors, hadron physics, neutrino physics, as well as theoretical nuclear and particle physics or other current topics. Practical experiments complement the theoretical knowledge.

Format of Teaching Lecture, Exercises, Seminar, Laboratory Work

Format of Examination Oral examination of 45 minutes

Requirements for the Attribution of Credit Points Passing the oral examination. The specialisation module must include: advanced laboratory courses (5 CP), a seminar (2 CP). Including the final oral module examination (2 CP), 15-25 CP can be achieved. Achievements made after the final module examination no longer count towards the module.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor Prof. Dr. Wiedner, Prof. Dr. Epelbaum

Examiner Prof. Dr. Afzal, Prof. Dr. Bulava, Prof. Dr. Epelbaum, Prof. Dr. Fritsch, Prof. Dr. Heinsius, Prof. Dr. Mikhasenko, Prof. Dr. Tjus, Prof. Dr. Wiedner, PD Dr. Krebs

Further Information For advice and coordination of the courses, please contact the module supervisor. Please see the course list below.

Course	Type	No.	Semester
Advanced Laboratory Course for Physics Students	Laboratory	160250	Winter Summer
Current Topics in the Standard Model and Beyond	Seminar	160429	Winter
Data Analysis in High Energy Physics	Lecture	160430	Winter
	Exercises	160431	
Detectors and Algorithms for Charged Track Reconstruction	Lecture with integrated Exercises	160412	Winter
Detectors for Particle Physics	Seminar	160421	Winter
Effective Field Theories	Seminar	160429	Summer
Experimental Methods in Nuclear and Particle Physics	Seminar	160420	Winter Summer
Hadron Physics	Lecture	160414	Summer
	Exercises	160415	
Hadrons at Large Hadron Collider	Seminar	160432	Winter Summer
Introduction into Chiral Perturbation Theory	Lecture	160427	Winter
	Exercises	160428	
Introduction to Nuclear and Particle Physics II	Lecture	160401	Summer
	Exercises	160402	
Introduction to Statistics for Astronomers and Physicists	Lecture	160613	Summer
Lattice Field Theory NEW	Lecture	160416	Summer
	Exercises	160417	
Nucleosynthesis in Nuclear Astrophysics	Lecture with Exercises	160424	Winter
Quantum Field Theory I	Lecture	160401	Winter
	Exercises	160402	
	Lecture	160403	Summer
	Exercises	160404	not in 25
Quantum Field Theory II	Lecture	160405	Summer
	Exercises	160406	
Particle Detectors for Hadron Physics Experiments	Lecture	160412	Summer
	Exercises	160413	
Particle Physics Detectors	Seminar	160421	Summer
Selected Topics of Hadron Physics I	Seminar	160422	Winter
Selected Topics of Hadron Physics II	Seminar	160426	Summer
Seminar on Hadron Physics	Seminar	160418	Winter
		160419	Summer
Symbolic Computation in Mathematica	Lecture	160406	Winter
		160411	Summer
Theoretical Hadron Physics	Lecture	160409	Summer
	Exercises	160410	not in 25
Theoretical Neutrino Astrophysics	Lecture	160616	Winter
	Exercises	160617	

Current Topics in the Standard Model and Beyond					
	Credits 2 CP	**Workload** 60 h	**Semester** from 1. Sem.	**Cycle** Winter	**Duration** 1 Semester
Courses a) Seminar Current Topics in the Standard Model and Beyond			**Contact Hours** a) 22 h	**Self-Study** 38 h	**Group Size** a) 30

Requirements for Participation
Formal None
Content Successful participation in the course Advanced Quantum Mechanics and Quantum Field Theory I and/or Introduction to Theoretical Hadron Physics will be advantageous.
Preparation None

Learning Outcomes
After successfully completing the module, the students
- are familiar with the basics of the Standard Model of particle physics, its successes and shortcomings as well as current research topics in particle physics
- Students have a deeper understanding of the scientific issues in the chosen focus area.
- students have experience in preparing and giving a scientific presentation.

Contents
The course deals with the fundamentals of the Standard Model and covers topics such as quantum chromodynamics, theory of the electroweak interaction, anomalies, QCD methods, precision tests of the Standard Model, neutrino physics, physics beyond the Standard Model, etc.
The seminar serves the elaboration of a concrete topic. At the beginning of the seminar, different topics will be handed out by the supervisors and briefly discussed. Within the seminar series, individual topics are developed and presented.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the sessions, presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Epelbaum,

Further Information

Data Analysis in High Energy Physics

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Data Analysis in High Energy Physics b) Exercises to Data Analysis in High Energy Physics	a) 22 h b) 11 h	a) 38 h b) 19 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content Proficiency in calculus and basic programming skills are recommended.
Preparation None

Learning Outcomes
After successfully completing the module, the students will be able to:

- understand the role and importance of data analysis in high-energy physics experiments
- apply basic and advanced statistical methods to particle physics data
- perform parameter estimation and hypothesis testing using real experimental data
- analyse and interpret uncertainties in experimental measurements
- utilize machine learning techniques for classification of particle reactions
- fit theoretical models to experimental data and evaluate quality of the fit
- gain hands-on experience with LHCb data and particle-physics analysis tools
- learn basics of Julia programming language
- complete an independent data analysis project, demonstrating the application of learned techniques
- present and effectively communicate analysis results to peers.

Contents
This course provides a comprehensive journey from statistical modelling to advanced data analysis techniques, incorporating elements of modern research workflows in particle physics. Students will learn core topics such as probability distributions, parameter estimation, hypothesis testing, uncertainty analysis, multivariate techniques, and machine learning for particle classification, alongside model fitting and evaluation. Weekly lectures will be followed by hands-on application to a freshly collected dataset from the LHCb experiment in 2024. Students will progressively build their skills by analysing real research data, fitting theoretical models, and interpreting uncertainties. The course also introduces Julia programming to equip students with modern computational tools. Bi-weekly tutorials will serve as hackathon-style workshops, providing direct support for advancing coding projects and preparing for upcoming tasks. By the end, students will complete an independent data analysis project and present their findings, demonstrating their proficiency in high-energy physics data analysis.

Format of Teaching Lecture, Exercises

Format of Examination Presentation of results of the data analysis project developed during the semester.

Requirements for the Attribution of Credit Points Active participation (> 75 %) the exercise, obtaining at least 50% of the possible points in the weekly exercises.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Mikhasenko

Further Information Recommended literature:

- "Data Analysis in High Energy Physics: A Practical Guide to Statistical Methods" by O. Behnke, K. Kröninger, G. Schott, and T. Schörner-Sadenius
- "Statistical Data Analysis" by Glen Cowan

Detectors for Particle Physics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Detectors for Particle Physics	a) 22 h	38 h	a) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
Students will
- Study individual subdetectors for subatomic particles
- Learn how complete detector systems are composed from subdetectors
- Understand the limitations of detectors
- Get acquainted with modern electronics and data acquisition systems
- Understand the interplay between physics goals and tailored experiments.

Contents
Detectors for charged and neutral particles with their advantages and drawbacks. The relevance of electronics and data acquisition systems for composed detector systems. The interplay between the source of subatomic particles and the design of a complete detector system tailored to very specific physics goals. Multipurpose detector systems at accelerators and their achievements.

Format of Teaching Seminar talks by the students

Format of Examination Preparation and subsequent presentation of a seminar talk to the whole group.

Requirements for the Attribution of Credit Points Independent preparation of a seminar talk about particle detectors and their physics goals. Clear and comprehensive presentation of the material to the seminar participants.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Wiedner, Prof. Dr. Heinsius

Further Information

Effective Field Theories

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Effective Field Theories	a) 22 h	38 h	a) 30

Requirements for Participation:
Formal None
Content Successful participation in the course Advanced Quantum Mechanics; participation in the lectures Quantum Field Theory I and/or Introduction to Theoretical Hadron Physics will be advantageous.
Preparation None

Learning Outcomes
After successfully completing the module, the students

- are familiar with the basics of effective field theories and their applications in nuclear and particle physics.
- Students have a deeper understanding of the scientific issues in the chosen focus area.
- students have experience in preparing and giving a scientific presentation.

Contents
The course deals with the basics of the theoretical methodology of effective field theories (EFT), which find wide application in almost all areas of physics. Topics include the interpretation of the Standard Model as EFT, pionless and chiral EFT, renormalisation and renormalisation group equation, EFT for the treatment of halo nuclei, EFT for BSM physics, EFT of gravity, etc.

The seminar is designed to work on a specific topic. At the beginning of the seminar, different topics are handed out by the supervisors and briefly discussed. Within the seminar series, individual topics are developed and presented.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the sessions, presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Epelbaum, PD Dr. Krebs

Further Information

Experimental Methods in Nuclear and Particle Physics					
	Credits 2 CP	**Workload** 60 h	**Semester** from 1. Sem.	**Cycle** Winter & Summer	**Duration** 1 Semester
Courses a) Seminar Experimental Methods in Nuclear and Particle Physics			**Contact Hours** a) 22 h	**Self-Study** 38 h	**Group Size** a) 30
Requirements for Participation **Formal** None **Content** None **Preparation** None					
Learning Outcomes Students will • get acquainted with certain physics topics in nuclear and particle physics • present the underlying theoretical concepts • learn the interpretation of experimental data • have a basic knowledge of nuclear and particle physics • be aware of the precision of measurements and the question of statistics					
Contents Strong and weak interactions. Heavy ion and neutrino physics. Quantum field theory as underlying theoretical concept. Statistical interpretation of data.					
Format of Teaching Seminar talks by the students.					
Format of Examination Preparation and subsequent presentation of a seminar talk to the whole group.					
Requirements for the Attribution of Credit Points Independent preparation of a seminar talk about particle detectors and their physics goals. Clear and comprehensive presentation of the material to the seminar participants.					
Use of the Module Courses in Physics Major					
Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP					
Module Supervisor and Instructor Prof. Dr. Wiedner					
Further Information					

Hadron Physics

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Hadron Physics b) Exercise for Hadron Physics	a) 22 h b) 22 h	76 h	a) unlimited b) 30

Requirements for Participation

Formal None

Content Prior completion of undergraduate-level courses in quantum mechanics, classical mechanics, and electromagnetism. Basic coursework in particle and nuclear physics is recommended.

Preparation Proficiency in calculus and basic programming skills are needed to effectively engage with the quantitative aspects of the course.

Learning Outcomes

After successful completion of the course, students will be able to

- demonstrate a solid understanding of the fundamental principles of QCD and its relation to the Quark Model (QM)
- describe the classification of hadrons, relation between flavour multiplets in Qm
- understand and discuss analysis of mass spectrum using reaction theory, characterize hadronic resonances and relate them to properties of particles
- develop skills in data analysis, including event generation and filtering
- gain insights into exotic hadrons like tetraquarks, pentaquarks, hybrid and glueballs
- follow discussions on application of effective field theories and computational methods (lattice QCD) in hadron physics
- identify current and future experiments in hadron physics, and understand the role in the broader context of particle physics
- identify potential research projects and opportunities for internships

Contents

This course in Hadron Physics is an extensive program designed to provide students with a fundamental and practical understanding of Quantum Chronodynamics (QCD) in a confined regime of hadronic matter. Beginning with the introduction to the basics of QCD, including quarks, gluons, colour confinement, asymptotic freedom, and gauge invariance, the course sets a solid theoretical foundation. It then progresses into a detailed study of hadron classification and structure, covering baryons, mesons, the quark model, and flavour symmetry. A significant portion of the course is devoted to experimental techniques in hadron physics, with a focus on particle detectors, and data processing, particularly LHCb, COMPASS, and BES experiments. This includes practical aspects of event generation, detection, and data analysis, alongside addressing common experimental challenges. Spectral analysis and reaction theory is explored, elucidating particle interaction, resonance phenomena. Students will also delve into the spectroscopy of hadrons, learning about excitation spectra of mesons and baryons, as well as exotic structures like tetraquarks, pentaquarks, glueballs, and hybrids. Theoretical tools and computational methods will be discussed in the second half of the course. The course also addresses current and future experiments in hadron physics, exploring their role in the broader context of particle physics and discussing heavy flavour physics, including heavy quarks, CP violation, and B-meson physics. Finally, the course wraps up with ethical and practical considerations in research, offering guidance on collaboration in large-scale experiments, student projects, research opportunities, and career paths in hadron physics.

Format of Teaching Lecture, exercises

Format of Examination An oral examination based on a demonstration of the solution to a problem

Requirements for the Attribution of Credit Points Active participation (> 50 %) in exercise classes, presentation of the homework problem at the board at least two times during the semester, oral exam of 30 minutes based on a problem communicated a week before the exam. The form of examination will be determined at the beginning of the course.
Use of the Module Courses in Physics Major
Importance of the Mark for the Final Grade Graded, but does not contribution to the weighted average final grade
Module Supervisor and Instructor Prof. Dr. Mikhasenko
Further Information Recommended literature: - F. Halzen and A.D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics - M. Thompson, Modern particle physics (2013) - A.D. Martin, T.D. Spearman, Elementary particle theory

Hadrons at Large Hadron Collider

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Hadrons at Large Hadron Collider	a) 22 h	76 h	a) Unlimited

Requirements for Participation
Formal None
Content Basic coursework in particle and nuclear physics is recommended.
Preparation None

Learning Outcomes
After a successful completion of the course, students will be able to:
- Gain an overview of state-of-the-art research topics related to studies of hadrons and their interactions at LHC
- Develop the ability to effectively present scientific research to a group of experts.
- Learn to actively participate in and contribute to scientific discussions

Contents
In this seminar, students are assigned a specific topic related to hadrons physics at Large Hadron Collider. Throughout the semester, they conduct an in-depth study of their topic following recent scientific publications. The first half of the course is dedicated to independent research, while students receive guidance and feedback from the instructor. In the second half, students present their findings to the group in a series of scientific presentations. These sessions are followed by open discussions.

Format of Teaching Seminar

Format of Examination The student performs a talk of 45-90 min. plus discussion within the research group

Requirements for the Attribution of Credit Points Active participation (> 75 %) and successful talk with valid discussion

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Mikhasenko

Further Information

Introduction to Nuclear and Particle Physics II					
	Credits 4 CP	**Workload** 120 h	**Semester** from 1. Sem.	**Cycle** Summer	**Duration** 1 Semester
Courses a) Lecture Introduction to Nuclear and Particle Physics II b) Exercises for Introduction to Nuclear and Particle Physics II			**Contact Hours** a) 22 h b) 22 h	**Self-Study** 76 h	**Group Size** a) Unlimited b) 30

Requirements for Participation
Formal None
Content Basic knowledge of nuclear physics.
Preparation None

Learning Outcomes
After a successful completion of the module

- Exists an over view over the Standard Model of Particle Physics.
- Can students describe the most important phenomena
- Are students acquainted with the experimental methods and techniques.
- Students have the knowledge of the basic principles of detectors for subatomic particles.
- Is the connection between theory and experiment clear.

Contents
Students will learn of the fundamental theoretical and experimental tools that lay the foundations of modern particle physics. The course will explain the connection between symmetries and quantum numbers. Details of the strong and weak interaction will be presented and their experimental observation in a historical context discussed. Important experimental discoveries and their consequences for the development of the field are part of the course including important breakthroughs like the discovery of the Higgs boson or the observation of neutrino oscillations. Also included is a look into the future to address open questions and the planned experiments and their goals.

Format of Teaching Lectures, exercises and short presentations of the students

Format of Examination Successful and regular participation in the exercise classes. In the homework section at least 50% of all possible points. Students are asked to present solutions to the problems at least twice during the semester to the group and are asked to present a short summary of the previous lecture twice.

Requirements for the Attribution of Credit Points Depending on the defined form of examination: The students need to obtain at least 50% of the possible points in the weekly practice assignments and participate actively in the discussion of the exercises. Also, twice a short summary of the previous lecture will be presented in class. In addition, the advanced practical exercises (F-Praktikum) are required. The grades from the lectures/exercises and the lab course enter both the grade of the module.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Wiedner

Further Information

Lattice Field Theory

	Credits	Workload	Semester	Cycle	Duration
	6 CP	180 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture “Introduction to Lattice Field Theory” b) Exercises “Introduction to Lattice Field Theory”	a) 44 h b) 22 h	114 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After a successful completion of the module, students

- have a basic understanding of the lattice regularization of quantum field theory, as well as application of the Markov chain Monte Carlo method
- are aware of the commonly used discretisation of QCD, as well as modern simulation algorithms
- know the theory of renormalisation and the elimination of leading cutoff effects
- are familiar with analysis techniques to determine hadron masses and matrix elements from simulation data
- can interpret statistical and systematic errors in lattice QCD computations associated with the finite lattice spacing and simulation volume

Contents
Review of continuum field theory, in particular Quantum Chromodynamics; Lattice regularisation of bosonic fields; the Fermion doubling problem and its solutions; the Symanzik improvement program; Chiral symmetry and associated Ward identities; Heatbath algorithm for pure gauge theory; Hybrid Monte Carlo algorithm for QCD; Multigrid inversion methods for the Dirac operator; Autocorrelation; Observables and Correlation functions; Real-time phenomena

Format of Teaching Lecture, exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written exam of 45 min, oral exam of 45 min or project work)

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written exam, the oral exam or successful project work

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Bulava

Further Information

Nucleosynthesis in Nuclear Astrophysics

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
c) Lecture Nucleosynthesis in Nuclear Astrophysics d) Exercises for Nucleosynthesis in Nuclear Astrophysics	c) 22 h d) 22 h	76 h	10

Requirements for Participation
Formal None
Content Basic knowledge of nuclear physics.
Preparation None

Learning Outcomes
After a successful completion of the module, students are familiar with

- the standard model of cosmology
- the evolution of stars depending on their mass
- the different production mechanisms of elementary particles in the different mass ranges
- the features of neutrinos

Contents
The lecture will start with an introduction into nuclear physics to provide the basic knowledge needed for the rest of the lecture. It will continue with a description of the big band and the big bang nucleosynthesis where the lightest elements are created. The next part of the lecture will describe the fusion processes in stars and their evolution which leads to the creation of more heavier elements up to iron. The third topic covers the creation of the more heavy elements via various different processes in supernovae and neutron star merges. The last part of the lecture covers our recent knowledge of neutrinos and their features.

Format of Teaching Lecture, exercises

Format of Examination Presentation about a topic selected at the beginning of the lecture

Requirements for the Attribution of Credit Points Successful presentation of a topic in a 25 – 30 minutes presentation and Active participation (>75 %) in the lecture.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Ritman, Dr. Stockmanns

Further Information

Selected Topics of Hadron Physics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar Selected Topics of Hadron Physics	a) 22 h	38 h	a) 30

Requirements for Participation:
Formal None
Content The seminar is aimed at Master and PhD students who are already familiar with the basics of quantum field theory, effective field theories and hadron physics.
Preparation None

Learning Outcomes
After successfully completing the module, the students
- have an overview of the current research directions and questions in the field of theoretical hadron physics.
- have experience in preparing and giving a scientific presentation.

Contents
The event deals with current developments in hadron physics. External experts are increasingly invited to provide the broadest possible overview of the research topics. Lectures are accompanied by intensive technical discussions and offer the opportunity to exchange ideas with the speakers. Scientific staff from the Department of Theoretical Hadron Physics also take part in the event.

The participating students and doctoral candidates have the opportunity to present their latest results and receive feedback.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the sessions, presentation

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Epelbaum, PD Dr. Krebs

Further Information

Seminar on Hadron Physics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar on Hadron Physics	a) 22 h	38 h	a) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successful completion of the module the students are

- are familiar with a selection of aspects in the field of Hadron Physics
- know the basic concepts of different detector technologies
- know the basic concepts of detector readout concepts and data processing
- leaned about different concepts of performing data analysis
- got an insight in a selection of historical important experiments and findings

Contents
Selected topics in the field of Hadron Physics: Detector Techniques, Detector Components, Data Acquisition and Detector Control System, Analysis methods, Data Analysis, Data Interpretation, historical important Physics topics

Format of Teaching Seminar

Format of Examination none

Requirements for the Attribution of Credit Points Regular attendance, at least 75% of the contact hours necessary, preparation and giving of one presentation. Only the Presentation is graded.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed with CP

Module Supervisor and Instructor Prof. Dr. Fritsch

Further Information

Plasma Physics

Modul 4e	Credits	Workload	Semester	Cycle	Duration
	15-25 CP	450-750 h	1.-2. Sem.	Winter & Summer	2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Lecture b) Exercises c) Seminar (at least 2 CP) d) Advanced Laboratory Courses (at least 5 CP) A complete overview of the courses can be found in the current course catalogue. The CP of the individual courses result from the semester hours per week (1 hour per semester week = 1 CP).	Each at least. a) 44 h b) 44 h c) 22 h d) 35 h	min. 309 h	a) unlimited b) 30 c) 30 d) 2

Requirements for Participation
Formal None
Content Basic knowledge of plasma physics will be expected
Preparation None

Learning Outcomes
After successfully completing the module, the students
- have a basic understanding of the important methods of plasma generation and the heating mechanisms of plasma
- are familiar with important diagnostic methods of plasma
- have a deepened understanding of the theoretical concepts to describe plasma in different scales of time and space
- can apply methods of measurement of plasma
- know different fields of application of plasma, like interaction with biological systems or with surfaces of fusion experiments

Contents
Plasma generation; plasma heating; plasma diagnostics; physics of the plasma boundary layer; plasma-surface interaction; plasma chemistry, plasma deposition, plasma etching; waves in plasmas, etc.

Format of Teaching Lecture, Exercises, Seminar, Laboratory Work

Format of Examination Oral examination of 45 minutes

Requirements for the Attribution of Credit Points Passing the oral examination. The specialisation module must include: advanced laboratory courses (5 CP), a seminar (2 CP). Including the final oral module examination (2 CP), 15-25 CP can be achieved. Achievements made after the final module examination no longer count towards the module.

Use of the Module Compulsory-Elective Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor Prof. Dr. von Keudell

Examiner Prof. Dr. Czarnetzki, Prof. Dr. Golda, Prof. Dr. Grauer, Prof. Dr. Innocenti, Prof. Dr. van Helden, Prof. Dr. von Keudell, Prof. Dr. Tjus, PD Dr. Fichtner

Further Information For advice and coordination of the courses, please contact the module supervisor. Please see the course list below.

Course	Type	No.	Semester
Advanced Laboratory Course for Physics Students	Laboratory	160250	Winter Summer
Applied Plasma Physics	Seminar	160522 160523	Winter Summer
Chaos, Turbulence and Stochastic Systems	Lecture Exercises	160532 160533	Summer
Compact Course: “Low Temperature Plasma Physics: Basis and Applications” and Master Class “Low Temperature Plasma Physics”	Compact Seminar	160523	Winter
Confinement Concepts and Advanced Materials for Extreme Environments	Lecture	160511	Winter
Ion Transport and Fluxes in Low-Temperature Plasmas	Lecture	160531	Summer not in 25
International School on Low Temperature Plasma Physics: Basics and Applications	Compact Seminar	160520	Summer not in 25
Introduction to Hydrodynamics	Lecture Exercises	160529 160530	Summer not in 25
Introduction to Nuclear Fusion – Plasma-Wall-Interactions and Plasma Edge Physics	Lecture	160513	Summer
Introduction to Plasma Physics II	Lecture Exercises	160501 160502	Winter
Introduction to Space Physics	Lecture Exercises	160618 160619	Winter
Local and Non-local Effects in Plasma Heating and Transport	Seminar	160518	Winter
Magnetohydrodynamic Turbulence and Reconnection	Lecture	160664	Summer not in 25
Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas	Lecture Exercises	160515 160516	Winter
Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II	Lecture Exercises	160511 160512	Summer
Plasma Chemistry	Lecture Exercises	160519 160520	Winter
Plasma Diagnostics	Lecture Exercises	160505 160506	Summer not in 25
Plasma Kinetics for Experimentalists	Seminar	160526	Winter
Problems of Modern Plasma Physics	Seminar	160521 160522	Winter Summer
Selected Topics of Plasma Theory	Seminar	160517	Winter
Selected Topics of Theoretical Plasma Physics	Seminar	160557	Summer
Seminar on Space Plasma Physics	Seminar	160558	Summer
Surface Physics and Chemistry	Lecture	160510	Summer
Turbulence and Transport in Fusion Plasmas	Lecture	160510	Winter
Space Plasma Physics	Lecture Exercises	160527 160528	Summer

Ion transport and fluxes in low-temperature plasmas

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Ion transport and fluxes in low-temperature plasmas	a) 22 h	38 h	a) Unlimited

Requirements for Participation
Formal None
Content Basic knowledge of the concepts and terminology of the Plasma physics are expected, e.g. through participation in the Module „Introduction to Plasma Physics“.
Preparation Participation in the lecture „Introduction to Plasma Physics II” is recommended, but is not mandatory.

Learning outcomes
After successful completion of the module

- the students have a fundamental understanding of the ion production, their collisional processes and the ion transport in non-magnetized low-temperature plasmas as well as of the influence of these processes on the spatial structure of the discharge.
- the students are familiar with the behaviour of plasmas with different levels of collisionality.
- the students know the fundamental concepts of sheaths and quasi-neutral plasmas.
- the students are familiar with the diagnostic methods for measuring the ion parameters of a plasma.
- the students are able to recognize the relations between the discharge conditions (pressure, type of gas, etc.) and plasma parameters (electron temperature and density) and can apply this knowledge for the estimation of the conditions in a laboratory plasma.

Contents

1. Ion production and loss processes
2. Ion collisional processes with charged and neutral particles
3. Ion transport in space charge sheaths
4. Kinetics of the ion transport
5. Ion transport and wave phenomena in plasmas
6. Experimental diagnostic methods

Format of Teaching Lecture

Format of Examination Oral examination within 45 min on given topics with a focus on one or two of these topics.

Requirements for the Attribution of the Credit Points Passing the oral examination

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module supervisor and instructor PD Dr. Tsankov

Further information The lecture will be in English. However, the oral examination may be held on request also in German.

Introduction to Plasma Physics II

	Credits	Workload	Semester	Cycle	Duration
	5 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Introduction to Plasma Physics II b) Exercises for Introduction to Plasma Physics II	a) 22 h b) 22 h	76 h	a) unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation Basic knowledge in the field of plasma physics, e.g. through the lecture "Introduction to Plasma Physics I" desirable but not mandatory.

Learning Outcomes

After successful completion of the module

1. students have a basic understanding of the essential characteristics of a low-temperature plasma
2. students know the heating methods and ignition phenomena of a plasma
3. students can assess the main fields of applications of low-temperature plasmas

Contents

1. Introduction: Overview of low-pressure plasmas, plasmas and their surface layers, plasma models, electrotechnical description
2. Generation of a plasma: ionization, swarm experiments, ignition of a plasma volume vs. surface mechanisms, ignition phenomena, sprites
3. Maintaining a Plasma: Ohmic Heating, Stochastic Heating, Wave Heating, Global Model for describing Plasmas, Electronegative Plasmas
4. Low pressure Plasmas: DC, RF, ECR, Magnetron, HPPMS
5. Atmospheric pressure plasmas: corona, DBD, microplasmas

Format of Teaching Lecture, Exercise

Format of Examination At the beginning of the course, the lecturer determines the form of examination (oral examination of 30 minutes or active participation in the exercises) for the lecture.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the exam/oral exam or obtaining at least 50% of the possible points in the weekly exercises. In addition, in this case, active participation in the exercise is mandatory. The form of examination will be determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Keudell

Further Information

Local and Non-Local Effects in Plasma Heating and Transport

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Local and Non-Local Effects in Plasma Heating and Transport	a) 44 h	76 h	a) unlimited

Requirements for Participation
Formal None
Content Introduction to Plasma Physics
Preparation None

Learning Outcomes
After successful completion of the module, students will

- have a basic understanding of kinetic and statistical methods in plasma physics
- be aware of possibilities related to non-local and resonant effects
- know the basic concepts of the statistical description of plasmas
- be familiar with the respective physical concepts and the mathematical methods
- be able to recognize the relation between temporal and spatial structures and their consequences for heating and transport

Contents
Plasma are many particle systems and, therefore, many phenomena cannot be described by the common fluid picture. In the course, the standard description by the Boltzmann equation is revisited in detail but a strong focus will be on alternative statistical concepts like the master equation, the Fokker-Planck equation and the Langevin equation. The concepts are derived from first principles and are then applied to describe basic plasma phenomena. These include, electron Landau damping, local and non-local electron heating in ICPs and the INCA discharge and non-local ion transport under charge exchange collisions. Mathematical methods as well as physical pictures and concepts are introduced. The theoretical concepts are complimented by experimental results.

Format of Teaching Lecture

Format of Examination Oral examination of 30 minutes

Requirements for the Attribution of Credit Points Successful passing of the oral examination

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Czarnetzki

Further Information

Magnetohydrodynamic Turbulence and Reconnection

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Magnetohydrodynamic Turbulence and Reconnection	a) 22 h	38 h	a) unlimited

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes

After successful completion of the module, students will

- have a basic understanding of MHD turbulence and reconnection
- are familiar with turbulent flows and magnetic reconnection

Contents

The MHD conservation laws are derived, after which some instabilities (Kelvin-Helmholtz, Rayleigh-Taylor, tearing, ...) are discussed. Subsequently, the MHD turbulence is introduced (Reynolds MHD, Esässer variable, ...). This is followed by the spectral properties (cascades, homogeneous and anisotropic turbulence, ...) and intermittency. Based on this, magnetic reconnection is introduced. The topology change as well as 2D and 3D reconnection are described. Current layers, SweetParker and Petschek reconnection are described in detail. In particular, shock-free reconnection is discussed.

Format of Teaching Lecture

Format of Examination At the beginning of the course, the lecturer determines the form of examination (an exercise certificate with weekly homework) for the lecture.

Requirements for the Attribution of Credit Points Achievement of at least 50 % of the possible points in the weekly homework assignments

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Dr. Scherer

Further Information

Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II b) Exercises for Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II	a) 22 h b) 22 h	76 h	a) unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students

- have a basic understanding of atomic processes relevant to spectroscopic investigations in laboratory and astrophysical plasmas.
- are aware of the possibilities of applying numerical methods in other areas of astrophysics and plasma physics.
- are familiar with the basic concepts of the Stroß radiation models and describe the important interrelationships of plasma spectroscopy.
- are familiar with modern methods of plasma spectroscopy as well as on-line tools like FLYCHK (https://nlte.nist.gov/FLY/) or atomic and spectroscopic database (https://physics.nist.gov/PhysRefData/ASD/lines_form.html)
- can recognise connections between atomic and plasma physics and apply them to different spectroscopic observations

Contents
The lecture summarises the basics of the atomic models of plasma spectroscopy. At first, relevant topics of atomic physics are explained, which are necessary for the understanding of the most important atomic processes. Previous knowledge from quantum mechanics is deepened. The most important processes are dealt with, which represent the foundation of plasma spectroscopy. Examples are taken from fusion and laboratory experiments and from astrophysics. The knowledge gained is partly supported by practical exercises using freely available atomic codes such as FLYCHK, FAC , or AUTOSTRUC-TURE, so that the listeners become familiar with the current status of atomic models and can apply them to their specific problems in research if required.

Format of Teaching Lecture, Exercises

Format of Examination Oral examination of 45 minutes

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the oral examination or obtaining at least 50% of the possible points in the weekly exercise tasks. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor PD Dr. Marchuk

Further Information

Plasma Chemistry

	Credits	Workload	Semester	Cycle	Duration
	3 CP	90 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Plasma Chemistry b) Exercises for Plasma Chemistry	a) 22 h b) 11 h	57 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content Introduction to Plasma Physics I + II
Preparation Introduction to Plasma Physics I + II

Learning Outcomes
After successfully completion of the course

- students have a basic understanding of equilibrium and non-equilibrium processes in plasma chemistry
- are aware of the possibilities plasma interactions offer for surface modifications and material processing
- students know the basic concepts of thermodynamics, kinetics, and reaction mechanisms in plasma environments
- are familiar with the mathematical description of kinetic models for plasma reactions and transport processes
- students are able to recognize connections between plasma chemistry and surface reactions, and apply this knowledge to real-world applications such as plasma etching and deposition

Contents
This course provides an introduction to the fundamental principles of plasma chemistry, focusing on the interaction between plasma and chemical processes. Topics include thermodynamics, kinetics, diffusion, surface reactions, and the behavior of ions in plasma environments. By the end of this course, students will be able to understand and apply these concepts to the study and manipulation of plasma-chemical systems.

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written exam of 90 min, oral exam of 30 min or in the form of exercises with weekly homework and active participation in the exercises).

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written exam, the oral exam or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation (> 75 %) in the exercises is also mandatory. The form of examination will be determined at the beginning of the course.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, but does not contribute to the weighted average final grade

Module Supervisor and Instructor Prof. Dr. Golda, Prof. Dr. von Keudell

Further Information

Plasma Diagnostics

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer (not in 25)	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Plasma Diagnostics b) Exercises for Plasma Diagnostics	a) 22 h b) 22 h	76 h	a) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully passing the module, the students
- Know the most important diagnostical methods
- Know to make the appropriate choice of a diagnostical method for the measurement of defined parameters of a plasma

Contents
The lecture introduces the fundamentals of optical plasma diagnostics. The essential plasma and atomic physical concepts are introduced. The lecture begins with the presentation of measurement and analysis of electrical parameters e.g., from a probe measurement. The spectroscopic methods are explained in detail, the parameters that can be directly and indirectly derived from them, e.g., electron density and temperature, are discussed, and the respective area of application as well as the limits of the methods are shown. Particular emphasis is also placed on teaching the experimental methodology, i.e., the mode of operation and use of optical components and devices. Finally, in addition to the optical methods, energy-resolved mass spectroscopy for the detection of atoms, molecules and ions is also dealt with.

Format of Teaching Lecture, Exercises

Format of Examination Delivery of a coursework The coursework can take the form of a written test or an interview with the lecturer.

Requirements for the Attribution of Credit Points Passing the examination with at least 50% of the achievable points.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Golda

Further Information

Seminar on Space Plasma Physics

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar on Space Plasma Physics	a) 22 h	38 h	a) unlimited

Requirements for Participation
Formal None
Content Knowledge of theoretical mechanics and electrodynamics
Preparation None

Learning Outcomes
After successfully passing the module, the students will
- have a basic understanding of plasma physics models relevant to space applications
- know fundamental parameter regimes of space plasma and their implications
- know key phenomena observed in Solar system plasmas
- have gained insight into key processes such as waves and instabilities
- be familiar with some theoretical concepts
- know fundamental methods in numerical space plasma simulation

Contents
- Short review of the description of magnetized plasmas
- Examples for plasma phenomena in space
- Formulation of theoretical models for these phenomena
- Fundamentals of numerical simulation of space plasma
- Overview over observational methods and technology

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Criteria to obtain CPs are:
i) regular and active participation in the seminar, and
ii) successful preparation and presentation of a 45 minute talk on a selected topic

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Prof. Dr. Innocenti / Dr. Dreher

Further Information

Turbulence and Transport in Fusion Plasmas

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Winter	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Lecture Turbulence and Transport in Fusion Plasmas	b) 22 h	38 h	b) Unlimited

Requirements for Participation
Formal None
Content None
Preparation Previous knowledge of plasma physics is useful

Learning Outcomes
After successfully passing the module, the students will

- know the basics of gyrokinetics
- have a basic understanding of linear, quasilinear and non-linear plasma modelling
- be able to program a simple simulation code
- be familiar with important plasma instabilities and saturations
- have application skills of transport equations for the purpose of comparing theory and experiment

Contents
Linear and non-linear physics of micro-instabilities and turbulence in magnetically confined plasmas, resulting heat and particle transport in fusion reactors

Format of Teaching Lecture and project seminar

Format of Examination Project work: Development of a scientific project within one week in small groups (2-3 persons), 15-20 minutes presentation on results; assessment of content and presentation quality. If desired, individual grades from the optional oral examination can be assessed at 50%.

Requirements for the Attribution of Credit Points Passing the examination. Active participation (>50% attendance) in the group project work and presentation.

Use of the Module Courses in Physics Major

Importance of the Mark for the Final Grade Graded, contribution to the final mark weighed for CP

Module Supervisor and Instructor Dr. Pueschel

Further Information Module is taught in English

Module 5: Elective Modules from the Catalogue for Minor Subjects

Modules amounting to 5-18 CP can be brought in from the range of other faculties and their subjects. However, should you plan to **write the Master's thesis in the minor subject**, 15 CP must be taken in the minor subject in which the thesis is written.

From the range of courses offered by the Faculty of **Chemistry and Biochemistry (Chemie und Biochemie)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Inorganic Chemistry (Anorganische Chemie)	Methods of Structure Analysis II (Methoden der Strukturanalyse II)	Summer (not in 25)	English
	Inorganic Chemistry II (Anorganische Chemie II)	Summer	German
	Block Courses Inorganic Chemistry (Anorganisch-Chemisches Grundpraktikum)	Summer	German
Biochemistry (Biochemie)	Biochemical Practical Course for Chemists (Biochemisches Praktikum für Chemiker/-innen)	Winter	German
	Introduction to Biochemistry (Einführung in die Biochemie)	Summer	German
	Biochemistry I (Biochemie I)	Winter	German
Physical Chemistry (Physikalische Chemie)	Compact Course: “Lasers and Optics” (Blockkurs: ”Laser und Optik”)	Winter	English
	Compact Course: ”Scanning Probe Microscopy” (Blockkurs: “Rastersondenmikroskopie”)	Winter	English
	Biophysical Chemistry I (Biophysikalische Chemie I)	Summer	English
	Biophysical Chemistry II (Biophysikalische Chemie II)	Winter	English
	Physical-Chemical Laboratory (Physikalisch-Chemisches Grundpraktikum)	Summer	German
	Physical Chemistry II (Physikalische Chemie II)	Summer	German
	Concepts of Spectroscopy and Introduction in Laser Spectroscopy (Konzepte der Spektroskopie und Einführung in die Laserspektroskopie)	Winter	English
	Concepts of Spectroscopy II (Konzepte der Spektroskopie II)	Summer	English
Industrial Chemistry (Technische Chemie)	Industrial Chemistry I (Technische Chemie I)	Winter	German
	Industrial Chemistry II (Technische Chemie II)	Winter	English
	Industrial-Chemical Laboratory (Technisch-Chemisches Praktikum)	Summer	German
Theoretical Chemistry (Theoretische Chemie)	Theoretical Chemistry I (Theoretische Chemie I)	Winter	German
	Theoretical Chemistry II (Theoretische Chemie II)	Winter	English
	Electronic and Molecular Structure Theory (Theoretical Chemistry III)	Summer	English
	Theoretical-Chemical Laboratory (Theoretisch-Chemisches Praktikum)	Summer	German

From the range of courses from the Faculty of **Geosciences (Geowissenschaften)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Geophysics*(Geophysik)	Reservoir Geophysics (Reservoirgeophysik)	Summer	English
	Rock Physics (Gesteinsphysik)	Summer	English
	Geophysical Practical (Geophysikalisches Praktikum)	Winter/ Summer	English
	Seismologic Data Analysis (Seismologische Datenanalyse)	Summer	English
	Seismic Waves: Theory and Numerical Modelling (Seismische Wellen: Theorie und numerische Mod-ellierung)	Summer	English
	Geophysical Inverse Problems (Geophysikalische inverse Probleme)	Winter	English
	Seismic and Electromagnetic Field Methods (Seismische und elektromagnetische Feldmethoden)	Winter	English
	Physics of Earth Materials (Physik der Erdmaterial-ien)	Winter	English
	Earthquake Seismology and the Seismic Cycle (Erdbebenseismology und der Erdbebenkreislauf)	Winter	English

*we recommend an in-person interview with the student counsellor of geophysics (Dr. Maria Kirchenbaur (Studienkoordination-gmg@ruhr-uni-bochum.de), before taking this minor subject!

From the range of courses from the Faculty of **Electrical Engineering and Information Technology (Elektrotechnik und Informationstechnik):**

Minor Subject:	**Modules**	**Semester**	**Language**
Plasmatechnology* (Plasmatechnik)	Plasmatechnology I (Plasmatechnik I)	Winter	German
	Fields, Waves and Particles (Felder, Wellen und Partikel)	Winter	German
Nanoelektronics** (Nanoelektronik)	Solid State Electronics (Festkörperelektronik)	Winter	German
	Nanoelektronics (Nanoelektronik)	Summer (not in 25)	German
Microelektronics (Mikroelektronik)	VLSI-Design (VLSI-Entwurf)	Winter	German
	Integrated Digital Circuits (Integrierte Digitalschaltungen)	Winter	German
Technology of Energy Systems (Energiesystemtechnik)	Introduction to Technology of Energy Systems (Einführung in die Energiesystemtechnik)	Winter	German
	Technology of Regenerative Electric Energy (Regenerative Elektrische Energietechnik)	Winter	German
Communication Technology (Kommunikationstechnik)	Systems of High Frequency Technology (Systeme der Hochfrequenztechnik)	Summer	German
	Digital Processing of Signals (Digitale Signalverarbeitung)	Winter	German
Medical Technology (Medizintechnik)	Ultrasound in Medicine (Ultraschall in der Medizin)	Winter	German
	Tomographical Imaging in Medicine (Tomographische Abbildungsverfahren in der Medizin)	Summer	German
	Image Processing in Medicine (Bildverarbeitung in der Medizin)	Summer	German

* ONLY if the specialisation in physics is NOT in plasma physics

** ONLY if the specialisation in physics is NOT in solid state physics

From the range of courses from the Faculty of **Mechanical Engineering (Maschinenbau)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Laser Application Technology* (Laseranwendungstechniken)	Laser Technology (Lasertechik)	Summer	German
	Laser Metrology (Lasermesstechnik)	Winter	German
	Laser Materials Processing (Laserfertigungstechik)	Summer	German
	Laser Medical Technology (Lasermediz-intechik)	Winter	German
Energy Systems and Energy Econo-mics (Energiesysteme und -wirt-schaft)	Energy Economics (Energiewirtschaft)	Summer	German
	Energy Conversion Systems (Energieumwandlungssysteme)	Winter	German
	Renewable Energy Systems (Erneuerbar Energiesysteme)	Winter	English
	Demand and Supply in Energy Markets (Angebot und Nachfrage in Energiemärkten)	Summer	English
	Energy Consumption and Life Cycle Assess-ment (Energieaufwendung und Ökobilanzie-rung)	Summer	German
	Nuclear Power Plants Engineering (Kernkraftwerkstechnik)	Winter	German
	Reactor Physics (Reaktortheorie)	Summer	German
Material Sciences (Werkstoffwissenschaften)	Materials – Fundamentals (Werkstoffe – Grundlagen)	Winter	German
	Material Science (Werkstoffwissenschaft)	Summer	German
	Polymers & Shape Memory Alloys (Polymere Werkstoffe und Formgedächnisle-gierungen)	Summer	German
	Light Metals and Composites Materials (Leichtmetalle und Verbundwerkstoffe)	Summer	German
	Electron Microscope and X-Ray Diffraction (Elektronenmikroskopie und Rönt-genbeugung)	Summer	German

*All examinations are oral Examinations. A personal registration is required

From the range of courses from the Faculty of **Mathematics (Mathematik)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Algebra (Algebra)	Algebra I (Algebra I)	Winter	German
	Algebra II (Algebra II)	Summer	German
	Number Theory (Zahlentheorie)	Summer	German
	Representation Theory (Darstellungstheorie)	Summer/ Winter	German
Geometry/Topology (Geometrie/Topologie)	Curves and Surfaces (Kurven und Flächen)	Summer	German
	Differential Geometry I (Differentialgeometrie I)	Winter	German
	Differential Geometry II (Differentialgeometrie II)	Summer	German
	Differential Topology (Differentialtopologie)	Summer (not in 25)	German
	Topology (Topologie)	Summer	German
	Algebraic Topology (Algebraische Topologie)	Irregularly	German
Analysis (Analysis)	Functional Analysis (Funktionalanalysis)	Summer	German
	Complex Analysis I (Funktionstheorie I)	Summer	German
	Complex Analysis II (Funktionsthoerie II)	Winter	German
	Ordinary Differential Equations (Gewöhnliche Differentialgleichungen)	Winter	German
	Partial Differential Equations (Partielle Differentialgleichungen)	Summer (not in 25)	German
Numerical Mathematics (Numerische Mathematik)	Numerics of Ordinary Differential Equations (Numerik gewöhnlicher DGLen)	Winter	German
	Numerics of Partial Differential Equations (Numerik partieller DGLen)	Summer	German
	Optimisation (Optimierung)	Irregularly	German
Probability Theory and Statistics (Wahrscheinlichkeitsthe-orie und Statistik)	Probability Theory I (Wahrscheinlichkeitsthoerie I)	Winter	German
	Probability Theory II (Wahrscheinlichkeitstheorie II)	Irregularly	German
	Statistics I (Statistik I)	Summer	German
	Statistics II (Statistik II)	Irregularly	German
	Mathematical Physics (Mathematische Physik)	Irregularly	German
	Introduction to Financial and Acturial Mathematics (Grundlagen der Finanz- und Versicherungsmathe-matik)	Summer	German
	Number Series (Zeitreihen)	Summer (not in 25)	German
Computer Science (Informatik)	Efficient Algorithms (Effiziente Algorithmen)	Summer	German

From the range of courses from the Faculty of **Computer Science (Informatik)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Computer Science (Informatik)	Complexity Theory (Komplexitätstheorie)	Irregularly	English
	Cryptography (Kryptographie)	Winter	German
	Computer Science II (Informatik II)	Summer	German
	Quantum Algorithms (Quantenalgorithmen)		
	Cryptanalysis (Kryptanalyse)	Summer (not in 25)	German
	Theory of Machine Learning (Theorie des maschinellen Lernens)	Summer	German
	Algorithmic Geometry (Geometrische Algorithmen)	Irregularly	German
	Cryptographic Protocols (Kryptographische Protokolle)	Summer	English
	Deep Learning	Winter	German
NEW from 01.10.24: not creditable (nicht anrechenbar)	Theoretical Computer Science (Theoretische Informatik – Informatik 3)	Winter	German
Computational Neurosci-ence (Neuroinformatik)	Computational Neuroscience: Neural Dynamics (Computergestützte Neurowissenschaft: Neurale Dy-namik)	Winter	English
	Computational Neuroscience: Vision and Memory (Computergestützte Neurowissenschaft: Vision und Gedächnis)	Summer	English
	Machine Learning: Unsupervised Methods (Maschinelles Lernen: Unüberwachte Methoden)	Winter	English
	Machine Learning: Supervised Methods (Maschinelles Lernen: Überwachte Methoden)	Summer (not in 25)	English
	Machine Learning: Evolutionary Algorithms (Maschinelles Lernen: Evolutionäre Algorithmen)	Winter	English
	Introduction to Perception (Einführung in die Wahrnehmung)	Irregularly	English
	The Neural Basis of Vision (seminar) (Die neuronalen Grundlagen des Sehens)	Irregularly	English
	Computational Cognitive Modeling (seminar) (Computergestützte kognitive Modellierung)	Irregularly	English
	Quantum Information and Computation	Winter	English

From the range of courses from the **ICAMS (Interdisciplinary Centre for Advanced Materials Simulations)**:

Minor Subject:	**Modules**	**Semester**	**Language**
Material Sciences (Materialwissenschaften)	Elements of Microstructure (Elemente der Mikrostruktur)	Winter	English
	Advanced Characterization Methods (Erweiterte Charakterisierungsmethoden)	Summer	English
	Materials Processing (Materialverarbeitung)	Winter	English
	Atomistic Simulation Methods (Atomistische Simulationsmethoden)	Winter	English
	Advanced Atomistic Simulation Methods (Fortgeschrittene atomistische Simulationsmethoden)	Winter	English
	Interfaces and Surfaces (Schnittstellen und Oberflächen)	Summer	English
	Application and Implementation of Electronic Structure Methods (Anwendung und Umsetzung von Methoden der elektronischen Struktur)	Winter	English
	Phase Field Theory and Application (Phasenfeldtheorie und Anwendung)	Summer (not in 25)	English
	Phase Field Theory II (Phasenfeldtheorie II)	Winter	English
	Programming Concepts in Materials Science (Programmierkonzepte in der Materialwissenschaft)	Winter	English
	Quantum Mechanics in Materials Science (Quantenmechanik in der Materialwissenschaft)	Summer	English
	Microstructure and Mechanical Properties (Mikrostruktur und mechanische Eigenschaften)	Summer	English
	Continuum Methods in Materials Science (Kontinuummethoden in der Materialwissenschaft)	Winter	English
	The CALPHAD Method in Thermodynamics and Diffusion (Die CALPHAD-Methode in Thermodynamik und Diffusion)	Summer	English
	Multiscale Mechanics of Materials (Multiskalige Mechanik der Materialien)	Winter	English
	Computational Fracture Mechanics (Computergestützte Bruchmechanik)	Winter	English
	Lattice Boltzmann Modelling: From Simple Flows to Interface Driven Phenomena (Lattice-Boltzmann-Modellierung: Von einfachen Strömungen zu grenzflächengetriebenen Phänomenen)	Winter	English
	Computational Plasticity (Plastische Berechnungen)	Summer	English
	Solidification Processing (Verfestigungsverfahren)	Winter	English
	Stochastic Processes (Stochastische Prozesse)	Irregularly	German

Computational Physics I

Module 6a	Credits 4 CP	Workload 120 h	Semester from 1. Sem.	Cycle Winter	Duration 1 Semester
Courses a) Lecture Computational Physics I b) Exercises for Computational Physics I			**Contact Hours** a) 22 h b) 22 h	**Self-Study** 76 h	**Group Size** a) Unlimited b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students
- have a basic understanding of fundamental numerical methods and procedures for dealing with physical problems
- are aware of the possibilities of concrete implementation and verification
- are familiar with the application to physical model problems

Contents
- Numerical differentiation and integration
- Ordinary and partial differential equations
- Linear systems of equations
- FFT
- Monte Carlo methods
- Practical exercises with Matlab, Python or Julia

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture.

Requirements for the attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Key Competences

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Innocenti

Further Information

Computational Physics II

Module 6b	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 1. Sem.	Summer	1 Semester

Courses	Contact Hours	Self-Study	Group size
a) Lecture Computational Physics II b) Exercises for Computational Physics II	a) 22 h b) 22 h	76 h	a) Unlimited b) 30

Requirements for Participation
Formal None
Content Knowledge from Computational Physics I will be appreciated
Preparation None

Learning Outcomes
After successfully completing the module, the students

- have a basic understanding of advanced numerical methods and applications in physics
- are aware of the possibilities and limitations of the use of numerical methods
- re familiar with the basic concepts of multiscale methods, stochastic differential equations, Monte Carlo methods
- are familiar with the possibilities of parallelisation

Contents

- Multiscale methods: FFT, Multigrid, Wavelets, Barnes-Hut, Fast Multipole Method, Particle in Cell methods (Boris-Push).
- Stochastic differential equations, Monte Carlo methods, Metropolis algorithm, Ising model
- Parallelisation: MPI, CUDA
- Finite Volume, Discontinues Galerkin

Format of Teaching Lecture, Exercises

Format of Examination At the beginning of the course, the lecturer determines the form of examination (written examination of 90 min, oral examination of 45 min or an exercise certificate with weekly homework and active participation in the exercises) for the lecture.

Requirements for the Attribution of Credit Points Depending on the specified form of examination: Passing the written/oral examination or obtaining at least 50% of the possible points in the weekly exercises. In this case, active participation in the exercise is also compulsory. The form of examination is determined at the beginning of the course.

Use of the Module Key Competences

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Innocenti

Further Information

Presentation Skills

Module 6c	Credits 2 CP	Workload 60 h	Semester from 1. Sem.	Cycle Summer	Duration 1 Semester
Courses a) Seminar “Presentation Skills”			**Contact Hours** a) 22 h	**Self-Study** 38 h	**Group size** a) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students
- have a basic understanding of how to structure a presentation
- learn how to engage their audience during a presentation
- know the basic concepts of body language
- know how to design their slides for a presentation

Contents
After an introduction on how to give a good presentation, students will practice to use the tools that were introduced. This includes preparing and practicing short talks outside of class and presenting them in class followed by feedback from the other students and the lecturer.

Format of Teaching Lecture, Seminar, Practical Exercises

Format of Examination Active participation in class is required, which includes giving feedback to the other students. The grade will be an average of the grades for short presentations given in class (80%) and active participation in the feedback rounds (20%).

Requirements for the Attribution of Credit Points Presentations given in class and participation in discussion and feedback round will be graded. Active participation (>75%) in the seminar is mandatory.

Use of the Module Key Competences

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Prof. Dr. Franckowiak

Further Information

Scientific English

Module 6d	Credits	Workload	Semester	Cycle	Duration
	5 CP	120 h	from 1. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Seminar English for Students of Physics and Astronomy and Other Subjects (from Level B1/B2) b) Online-Exercises	a) 22 h	98 h	a) 30 b) Unlimited

Requirements for Participation
Formal Proof of language aptitude through an entrance test (cf. www.zfa.rub.de)
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students
- can present themselves, their studies and their interests in a concise and comprehensible way
- can extract important information from specialised texts by using specific reading techniques. They can use such extracted quotations and evidence to defend their own point of view
- Students can work out the function and form of different types of texts and apply this knowledge competently in self-produced texts
- can understand both essential and detailed information from listening and reading texts and communicate this clearly, precisely, and concisely to others, both orally and in writing
- are able to make a topic of interest accessible to non-experts (laypersons) in a lecture and to answer questions on it
- re able to express and ask for personal points of view and opinions, formulate arguments and counter-arguments and point out advantages and disadvantages in a discussion on specialised topics and topics of their own interest

Contents
The course is divided into a face-to-face phase (2 hours) and an online phase (freely divisible practice times). The focus of the face-to-face course is on the communicative use of language in reception, production, interaction and mediation, both in written and spoken form. Various reading strategies are taught and applied, and students work with authentic audio and visual texts on Moodle. Furthermore, the specific vocabulary in the field of physics and astronomy is trained. Blended Learning: The course is accompanied by a specific e-learning offer, which is an integral part of the course. It therefore consists of two parts:
1. face-to-face course.
2. moodle course in blended learning format, in which, with the help of the materials provided
4-5 different types of texts are written and revised on the basis of individual feedback

Format of Teaching Seminar, practical exercises

Format of Examination Presentation, written portfolio, Listening-discussion test of c. 30 min

Requirements for the Attribution of Credit Points Active participation in the seminars (>75%), passing the examination

Use of the Module Key Competences

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Mariano

Further Information This module is offered by the Centre of Education in Foreign Languages (www.zfa.rub.de).

List of Additional Key Competences

In justified exceptional cases, modules that are not in this module handbook may also be recognised. For this purpose, a justified request must be submitted to the study advisor (Dr. Ivonne Möller).

Note on Programming Languages:

All modules that deepen a programming language (C, C++, Python, Java, PHP or Modula) can be chosen from the RUB's offer (e.g. the module "Computer Science I (from winter semester 21/22: "Programming for ITS") on the programming language TScript). However, modules that only represent a basic introduction to the understanding of programming techniques cannot be credited in the M.Sc. in Physics.

From the catalogue of the Faculty of **Computer Science (Informatik):**

Module	Credits	Semester	Frequency / Further Information	Duration	Language
Information Theory (VVZ-Nr.: 211007)	5 CP	Summer	https://qi.rub.de/it_ss23 <https://qi.ruhr-uni-bochum.de/it_ss23>)	1 Semester	English

From the catalogue of **RUBION**:

Module	Workload/Credits	Semester	Frequency	Duration	Language
Basic Course in Radiation Protection according S4.1 (Grundkurs im Strahlenschutz nach der Fachgruppe S4.1)	150 h/5 CP	Winter/ Summer	s. RUBION	Block Course	German

From the catalogue of the **Academic Writing Centre (Schreibzentrum)**:

Module	Credits	Semester	Frequency	Duration	Language
Intensive Module Theses in Science and Engineering (Intensivmodul Abschlussarbeiten in den Naturwissenschaften A oder B)	5 CP	Winter/ Summer	s. SCHREIBZENTRUM	1 Semester	German

From the catalogue of the faculty of **Economic Sciences (Wirtschaftswissenschaften)**:

Module	Credits	Semester	Language
Fundamentals of Finance and Investment (Corporate Finance I: Finanzierung & Investition)	5 CP	Summer	German
Financial Risk Management (Corporate Finance II: Finanzielles Risikomanagment)	5 CP	Summer	German
Capital Market Theory (Corporate Finance III: Kapitalmarkttheorie)	5 CP	Winter	German
Basics of Starting a Business (Start-Up I: Grundlagen der Existenzgründung)	5 CP	Winter	German
Coaching-Workshop for Start-Ups (Start-Up II: Coaching-Workshop für Existenzgründer)	5 CP	Winter/Summer	German
Basics of Business Plan Preparation (Start-Up III: Grundlagen der Businessplanerstellung)	5 CP	Summer	German

Project Management

Module 7	Credits 5 CP	Workload 150 h	Semester from 1. Sem.	Cycle Summer	Duration 1 Semester
Courses a) Seminar Project Management b) Practical exercises Project Management			**Contact Hours** a) 50 h b) 50 h	**Self-Study** 50 h	**Group Size** a) 30 b) 30

Requirements for Participation
Formal None
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students
- are familiar with the basics of project management
- have a basic understanding of leading a team
- can plan a scientific project and guide its implementation
- can adhere to time and formal frameworks

Contents
a) The seminar dates serve on the one hand to teach the basic methodological skills for project and team management. On the other hand, results from the practical exercises are discussed and problems analysed. The focus is on the exchange of information and feedback from the module supervisor. Leadership protocols and progress reports are prepared.
b) In the practical exercises, the participants have the opportunity to apply the acquired knowledge to a group of Bachelor students and to guide them in the implementation of a SOWAS project. From the preparation of the exposés to the final poster presentation, the participants of this module support the SOWAS students both professionally and interdisciplinarily.

Format of Teaching Seminar, practical exercises

Format of Examination Presentation, active participation

Requirements for the Attribution of Credit Points active participation in the seminar (>75 %), active participation in the exercises (> 75 %)

Use of the Module Mandatory Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Lecturers of the faculty

Further Information Alternatively, this module can be replaced by the module "Key competences for project processing and self-organisation", which is offered via the RUB Writing Centre, upon justified written request.
Further Information: www. http://www.sz.rub.de/angebote/studierende/seminare/sps.html

Knowledge of Methods and Planning of the Project

Module 8	Credits	Workload	Semester	Cycle	Duration
	15 CP	450 h	from 3. Sem.	Winter & Summer	1 Semester

Courses	Contact Hours	Self-Study	Group Size
a) Practical exercises b) Seminar	a) 320 h b) 30 h	100 h	a) 30 b) 30

Requirements for Participation
Formal Admission to the Master's thesis has been granted, i.e. academic achievements amounting to at least 50 CP must be proven (including an elective module from experimental physics (9 CP), an in-depth module from theoretical physics (6 CP), the specialisation module (15-25 CP) and the compulsory module "project management" (5 CP)). If the thesis is to be written in the minor subject, at least 15 CP from the minor subject must be proven.
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students

- are immediately familiar with the experimental equipment, theoretical models and computer codes from their subject area
- have a deeper understanding of the scientific issues in their chosen field of specialisation
- are familiar with the most important concepts of time management and project work
- can plan the upcoming Master's thesis in terms of time and content

Contents
a) In the practical exercises, the required concrete working methods of the group are learned. After an intensive familiarisation phase, the students have the opportunity to participate in the concretisation of their topic for the Master's thesis. In addition, a timetable for the implementation of the Master's thesis is drawn up and its feasibility is checked.
b) The seminar serves to develop a concrete topic for the Master's thesis. At the beginning of the seminar, various topics are given out by the supervisors. Individual topics are developed within the seminar series.

Format of Teaching Practical exercises, Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the exercises, individual presentation

Use of the Module Mandatory Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Professors and private lecturers of the Faculty of Physics and Astronomy. Upon application, other examiners may be admitted if necessary.

Further Information The module belongs to the module "Master's thesis" in terms of content and subject matter. Both modules are completed with the same lecturer. With the admission to the Master's thesis, the preparation period of 3 months begins, which includes the module "Knowledge of Methods and Project Planning (M.Sc.)". At the end of the preparation period, the module certificate must be submitted to the examination office together with a topic proposal.

Project Seminar for the Master's Thesis

Module 9	Credits	Workload	Semester	Cycle	Duration
	15 CP	450 h	3. & 4. Sem.	Winter & Summer	2 Semesters

Courses	Contact Hours	Self-Study	Group Size
a) Seminar A b) Seminar B	a) 100 h b) 30 h	320 h	a) 30 b) 30

Requirements for Participation
Formal Proof of completion of the module "Knowledge of Methods and Planning a Project"
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students

- can document the current status of their project "Master's thesis" (on a weekly and monthly scale)
- can analyse successes, problems and difficulties and work out suggestions for the next project step
- have a basic understanding of how to communicate subject content appropriately (orally and in writing)

Contents

a) Seminar A takes place weekly, also during the lecture-free period. Each student first reports on the results of the previous week and analyses the progress and difficulties. The result of this analysis should be the starting point for further planning. The explanations or arguments can be supported by graphs or a presentation. The group discusses the feasibility in terms of time and content with the aim of designing the next work steps as effectively as possible.
b) In seminar B, the project "Master's thesis" is presented in the respective working group. The presentation can be given either in the middle of the Master's thesis as an "interim report" or at the end as a "final report". The individual project phases as well as the time planning and implementation are in the foreground in addition to the focal points of the content.

Format of Teaching Seminar

Format of Examination Presentation

Requirements for the Attribution of Credit Points Active participation in the exercises, individual presentation

Use of the Module Mandatory Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Professors and private lecturers of the Faculty of Physics and Astronomy. Upon application, other examiners may be admitted if necessary.

Further Information This module is taken at the same time as the module "Master's thesis" and is taken with the same lecturer. The module certificate is submitted to the examination office together with the thesis.

Master's Thesis

Module 10	Credits	Workload	Semester	Cycle	Duration
	30 CP	900 h	3. & 4. Sem.	Winter & Summer	2 Semester

Courses	Contact Hours	Self-Study	Group Size
Thesis	720 h	180 h	1

Requirements for Participation
Formal Proof of completion of the module "Knowledge of Methods and Planning a Project"
Content None
Preparation None

Learning Outcomes
After successfully completing the module, the students
- have a deeper understanding of scientific ways of thinking and working
- are able to analyse physical questions and solve defined problems using scientific methods within a given period of time
- are aware of the requirements of an appropriate, written presentation of demanding and novel scientific results
- are familiar with the most important concepts of independent work organisation
- are familiar with adequate literature research, citation of sources and the principles of good scientific practice

Contents
Independent construction of an experiment or a theoretical model, independent planning and execution of the experiments or calculations/simulations, analysis of the results, optimisation of the processes, documentation of the process steps.
The topic and task must be formulated in such a way that they can be completed within 9 months with a workload of 30 CP.

Format of Teaching

Format of Examination Writing a scientific paper

Requirements for the Attribution of Credit Points Passing the examination

Use of the Module Mandatory Module

Importance of the Mark for the Final Grade Weighted according to Credit Points

Module Supervisor and Instructor Professors and private lecturers of the Faculty of Physics and Astronomy. Upon application, other examiners may be admitted if necessary.

Further Information The Master's thesis must be written in the chosen physics specialisation in which the specialisation module was completed. In addition, it is possible to write the thesis in a minor subject upon application.