RUHR
UNIVERSITÄT
BOCHUM

RUB

Faculty of Physics and Astronomy

Preliminary modul manual

Master of Science (M.Sc.) in Physics

PO 2021

Ruhr-Universität Bochum

Warning: Preliminary version, changes may still apply!

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. Compulsory modules amounting to 60 CP cover the subject-specific and interdisciplinary preparation and execution of the final thesis. The compulsory elective area includes 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, plasma physics). In the area of key competences, further modules of up to 10 CP can be selected. A list of the approved modules can be found in this module handbook.

The division of the 120 CP to be completed into the modules in the physics degree programme is illustrated in the following table (see end of document for full size).

Master of Science	Semester	Experimentalphysik	Theoretische Physik	Schwerpunkt	Nebenfach	Schlüsselkompetenzen	Masterarbeit
		9-18 CP	6-15 CP	15-25 CP	5-18 CP	5-15 CP	60 CP
Vertiefungsphase	1	Wahlpflichtmodule aus der Experimentalphysik (z.B. Astro/Bio/FK/KT/Plasma) 1 VL + 3 FP	Wahlpflichtmodule aus der Theoretischen Physik (z.B. ART/Statistik/QM II)	Spezialvorlesung/Seminar/Praktikum (Astro/Bio/FK/KT/Plasma) Pflicht: 5 FP, 1 Seminar (mündl. Prüfung 2 CP)	Module aus anderen Fakultäten	z.B. C++ oder Scientific Writing 0-10 CP	
	2	Wahlpflichtmodule aus der Experimentalphysik (z.B. Astro/Bio/FK/KT/Plasma) 1 VL + 3 FP	Wahlpflichtmodule aus der Theoretischen Physik (z.B. Astro/FK/Plasma) 1 VL + 3 FP		Module aus anderen Fakultäten	Projektleitung 5 CP	
Forschungsphase	3						Methodenkenntnis und Projektplanung 15 CP; Projektseminar zur MA-Arbeit 15 CP
	4						MA-Arbeit 30 CP

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:

Dr. Ivonne Möller (General Questions)
NB 02/172
Fon.: +49(0)234-32-29105
master-international@physik.rub.de

Dr. Andreas Kreyssig (for International Students
NB 4/…
Fon.: +49(0)234-32-…
master-international@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 -12 CP	One (or two) module(s) from "Statistical Physics", "Advanced Quantum Mechanics" and "General Theory of Relativity	1.+2.	Graded, via a module final examination or an oral examination. One module from 2a to 2c (at choice) must be completed. A further module 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	Projektmanagement	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 4e) 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 period.

4. List of all modules:

Modul 1 (Wahlpflichtmodule aus der Experimentalphysik)

Modul 2 (Wahlpflichtmodule aus der Theoretischen Physik)

Modul 3 (Wahlmodule aus der Theoretischen Physik)

Modul 4 (Wahlpflichtmodule für den Schwerpunkt)

Modul 5 (Wahlpflichtmodule für das Nebenfach)

Modul 6 (Wahlmodule für den Bereich Schlüsselkompetenzen)

Pflichtmodule

Introduction to Astrophysics

Module 1a	Credits 9 CP	Workload 270 h	Semester from 1. Sem.	Cycle Summer Term	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** Students a) unbegrenzt b) 30 c) 2

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module

Importance of the Mark for the Final Mark Weighed according to credit points

Module Supervisor and Instructor Prof. Dr. Dettmar

Further Information

Introduction to Biophysics

Module 1b	Credits	Workload	Semester	Cycle	Duration
	9 CP	270 h	from 5. Sem.	Winter Term	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	Studierende a) unbegrenzt b) 30 c) 2

Requirements fro Participation
Formal: none
Content-Wise: Basic knowledge in Physics I-III (Bachelor) will be highly appreciated
Preparation: none

Leaning 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.

Utilisation of the Module Compulsory-Elective Module

Importance of the Mark for the Final Mark Weighed 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 5. Sem.	Winter Term	1-2 Semesters

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

Requirements fro Participation
Formal: none
Content-Wise: 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
- (klassisches freies Elektronengas, Fermi-Dirac-Verteilung, elektrische Leitfähigkeit, thermische Eigenschaften von Leitern, metallische Bindung, Ladungsträger im Magnetfeld, Bändermodell, experimentelle Bestimmung der Bandlücken, Halbleiter, thermische Anregung von Ladungsträgern, effektive Masse, Löcherleitung, Störstellenleitung, pn-Übergang)

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.
Utilisation of the Module Compulsory-Elective Module
Importance of the Mark for the Final Mark Weighed according to credit points
Module Supervisor and Instructor Prof. Dr. Böhmer
Further Information

Introduction to Nuclear and Particle Physics

Module 1d	Credits	Workload	Semester	Cylce	Duration
	9 CP	270 h	from 5. Sem.	Winter Term	1-2 Semesters

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

Requirements for Participation

Formal: none

Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module
Importance of the Mark for the Final Mark Weighed 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 4. Sem.	Summer Term	1-2 Semesters

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

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Dr. Tsankov

Further Information

General Relativity

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

Requirements for Participation
Formal: none
Content-Wise: 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; Dif-ferential 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

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Prof. Dr. Grauer

Further Information Unfortunately, the module is not offered at the RUB in summer semester 22. Alternatively, the module can be taken at TU Dortmund.

Advanced Quantum Mechanics

Modul 2b	Credits	Workload	Semester	Cycle	Duration
	6 CP	180 h	ab 5. Sem.	Winter Term	1 Semester

Courses	Contact Hours	Self Study	Group Size
a) Lecture Advanced Quantum Mechanics b) Exercises Advanced Quantum Mechanics	a) 44 h b) 22 h	114 h	Students a) unlimited b) 30

Requirements for Participation

Formal: none

Content-Wise: 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

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Prof. Dr. Grauer

Further Information

Statistical Physics					
Modul 2c	**Credits** 6 CP	**Workload** 180 h	**Semester** from 6. Sem.	**Cycle** Summer Term	**Duration** 1 Semester
Courses a) Lecture Statistical Physics b) Exercises Statistical Physics			**Contact Hours** a) 44 h b) 22 h	**Self Study** 114 h	**Group Size** Students a) unlimited b) 30

Requirements for Participation
Formal: none
Content-Wise: 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

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Prof. Dr. Sulpizi

Further Information

Introduction to Theoretical Astrophysics

Modul 3a	Credits 6 CP	Workload 180 h	Semester From 5. Sem.	Cycle Summer Term	Dauer 1 Semester
Courses a) Lecture Introduction to Theoretical Astrophysics b) Exercises Introduction to Theoretical Astrophysics			**Contact Hours** a) 44 h b) 22 h	**Self Study** 114 h	**Group Size** Students a) unlimited b) 30

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Prof. Dr. Tjus

Further Information

Introduction to Theoretical Solid State Physics

Modul 3b	Credits	Workload	Semester	Cycle	Duration
	6 CP	180 h	from 5. Sem.	Winter Term	1 Semester

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

Requirements for Participition
Formal: none
Content-Wise: 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 Examinarion 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.

Utilisation of the Module Compulsory-Elective Module
Importance of the Mark for the Final Mark Weighed according to Credit Points
Module Supervisor and Instructor Prof. Dr. Eremin
Further Information

Introduction to Theoretical Plasma Physics					
Modul 3c	**Credits** 6 CP	**Workload** 180 h	**Semester** from 5. Sem.	**Cycle** Winter Term	**Duration** 1 Semester
Courses a) Lecture Introduction to Theoretical Plasma Physics b) Exercises Introduction to Theoretical Plasma Physics			**Contact Hours** a) 44 h b) 22 h	**Self Study** 114 h	**Group Size** Students a) unlimited b) 30

Requirements for Participation

Formal: none

Content-Wise: Basic knowledge of theoretical physics, especially electrodynamics (Bachelor level), is highly appreciated

Preparation: none

Lernziele (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 Examinarion 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.

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor and Instructor Dr. Scherer

Further Information

Astrophysics/Astronomy					
Modul 4a	**Credits** 15-25 CP	**Workload** 450-750 h	**Semester** 1.-2. Sem.	**Cycle** Winter & Summer Term	**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** mind. 309 h	**Group Size** Students a) unlimited b) 30 c) 30 d) 2

Requirements for Participation
Formal: none
Content-Wise: Basic knowledge of astronomy/astrophysics will be expected
Preparation: none

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

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.

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.
Utilisation of the Module Compulsory-Elective Module
Importance of the Mark for the Final Mark Weighed according to Credit Points
Module Supervisor Prof. Dr. Bomans
Examiners Prof. Dr. Bomans, Prof. Dr. Dettmar, Prof. Dr. Franckowiak, Prof. Dr. Hildebrandt, 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.

Winter Semester

160611 **Cosmology (Lecture)** Hildebrandt, Hendrik *Lecture*
160612 **Cosmology (Exercises)** Hildebrandt, Hendrik *Exercises*
160623 **Astrophysical Fluids, Plasmas and Shocks** Scherer, Klaus *Lecture*
160613 **Radio Astronomy** Adebahr, Björn *Lecture*
160608 **Stars, Winds, Nebulae** Weis, Kerstin *Lecture*
160602 **The Milky Way and External Galaxies** Bomans, Dominik J. *Lecture*
160621 **Selected Topics of Astronomy** Bomans, Dominik J.; Dettmar, Ralf-Jürgen; Franckowiak, Anna; Hildebrandt, Hendrik *Seminar*
160656 **Selected Topics on High Energy Particle Astrophysics** Tjus, Julia *Seminar*
160624 **Advanced Laboratory: Observational Astronomy** Dettmar, Ralf-Jürgen; Bomans, Dominik J.; Franckowiak, Anna *Laboratory*
160615 **Fluid Dynamics in Astrophysics** Scherer, Klaus *Lecture*
160616 **Theoretical Neutrino Astrophysics** Tjus, Julia *Lecture*
160617 **Theoretical Neutrino Astrophysics (Exercises)** Tjus, Julia; Merten, Lukas *Exercises*
160618 **Introduction to Space Physics** Fichtner, Horst *Lecture*
160619 **Introduction to Space Physics (Exercises)** Fichtner, Horst *Exercises*
160609 **Theoretical Heliophysics** Fichtner, Horst; Kleimann, Jens *Seminar*
160663 **Research Topics in Heliophysics** Fichtner, Horst *Seminar*
160610 **Methods in Theoretical Astroparticle Physics** Tjus, Julia *Seminar*
160661 **Observational Cosmology** Hildebrandt, Hendrik *Seminar*
160665 **Crossing the Desert** Rhode, Wolfgang *Seminar*
160666 **Multi-Wavelength Astrophysics** Franckowiak, Anna *Seminar*
160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*
160651 **Extragalactic Astronomy** Dettmar, Ralf-Jürgen *Seminar*

Summer Semester:

160601 **Interstellar Medium Astrophysics** Bomans, Dominik J. *Lecture*
160614 **Astroparticle Physics** Franckowiak, Anna *Lecture*
160615 **Astroparticle Physics (Exercises)** Franckowiak, Anna *Exercises*
160660 **Variabilities and Instabilities in Stars** Weis, Kerstin *Lecture*
160613 **Introduction to Statistics for Astronomers and Physicists** Wright, Angus *Lecture*
160511 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II** Marchuk, Oleksandr *Lecture*
160512 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II (Exercises)** Marchuk, Oleksandr *Exercises*
160664 **Magnetohydrodynamic Turbulence and Reconnection** Scherer, Klaus *Lecture*
160620 **Selected Topics of Astronomy II (Seminar)** Hildebrandt, Hendrik; Dettmar, Ralf-

Jürgen; Bomans, Dominik J.; Franckowiak, Anna			*Seminar*
160662	**Multi-Wavelength Astrophysics**	Franckowiak, Anna	*Seminar*
160650	**Observational Cosmology (Seminar)**	Hildebrandt, Hendrik	*Seminar*
160661	**Crossing the Desert**	Hildebrandt, Hendrik	*Seminar*
160623	**Methods in Theoretical Astroparticle Physics (Seminar)**	Tjus, Julia	*Seminar*
160624	**Theoretical Heliophysics (Seminar)**	Fichtner, Horst; Kleimann, Jens	*Seminar*
160626	**Astronomisches Beobachtungs-Praktikum / Laboratory: Observational astronomy**	Bomans, Dominik J.; Dettmar, Ralf-Jürgen	*Laboratory*
160250	**Fortgeschrittenen-Praktikum für Physikerinnen und Physiker / Advanced Laboratory Course for Physics Students**	Reicherz, Gerhard; Krebs, Hermann	*Laboratory*
160610	**X-ray Astronomy**	Bomans, Dominik J.	*Lecture*

Cosmology

	Credits	Workload	Semester	Turnus	DURATION
	4 CP	120 h	1. Sem.	WiSe	1 Semester

Courses	Kontaktzeit	Selbststudium	Group size
a) Lecture „Cosmology (Lecture)“ b) Exercise „Cosmology (Exercices)“	a) 33 h b) 11 h	a) 76 h	Students a) Unlimited b) 30

Participation requirements
Formal: none
Content: Introduction to Astronomy
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 basics of the inflationary universe, reionisation, gravitational lensing, and galaxy evolution,
- are ready to work on a master thesis with a cosmological topic.

Content
The lecture course 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, reionisation, gravitational lensing, and galaxy evolution are covered, always with a focus on connecting theoretical cosmology with observations.

Teaching forms lecture, exercise class

Forms of examination oral exam

Requirements for the award 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Hendrik Hildebrandt

Other information

Extragalactic Astronomy					
	Credits 2 CP	**Workload** 60 h	**Semester** 3. / 4. Sem.	**Turnus** WiSe / SoSe	**DURATION** 1 Semester
Courses a) Seminar „Extragalactic Astronomy“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited

Participation requirements
Formal: private inquiry
Content: none
Preparation: Introductory lectures in astronomy and astrophysics

Learning outcomes
After successful completion of the modul
- students have a basic understanding of current research projects at the chair of astronomy
- students know the basic concepts of research in the field of extragalactic astronomy
- are familiar with the various observational and data reduction techniques and methods used
- students are able to critically assess the impact of a publication and judge the importance for their own research project

Content
Significant and topical publications are presented and reviewed in the context of ongoing projects conducted at the chair of astronomy. The importance of papers is discussed with regards to the ongoing projects.

Teaching forms Seminar

Forms of examination Presentation

Requirements for the award of credit points Active participation and presentation

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Ralf-Jürgen Dettmar

Other information

The Milky Way and External Galaxies					
	Credits 3 CP	**Workload** 90 h	**Semester** 5. / 7. Sem.	**Turnus** WiSe	**DURATION** 1 Semester
Courses a) Lecture „The Milky Way and External Galaxies“			**Kontaktzeit** a) 33 h	**Selbststudium** a) 57 h	**Group size** Students a) Unlimited

Participation requirements
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 Astrphysics“ 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.

Content
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, starformation history, and chemical evolution will be presented and applied to the different galaxy types and conclusions for the evolution of the galaxy types derived.

Teaching forms lecture

Forms of examination usually a short oral presentation, alternatively (if special conditions apply) a written essay or an oral exam

Requirements for the award of credit points
active participation and a successful examination

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Dominik Bomans

Other information

Multi-Wavelength Astrophysics

	Credits	Workload	Semester	Turnus	DURATION
	2 CP	60 h	1. / 2. Sem.	WiSe / SoSe	1 Semester
Courses b) Seminar „Multi-Wavelength Astrophysics“			**Kontaktzeit** b) 22 h	**Selbststudium** b) 38 h	**Group size** Students b) Unlimited

Participation requirements
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

Content
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 modeling 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.

Teaching forms Seminar

Forms 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 award 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Anna Franckowiak

Other information

Observational Cosmology

	Credits	Workload	Semester	Turnus	DURATION
	2 CP	60 h	3. / 4. Sem.	WiSe / SoSe	1 Semester

Courses	Kontaktzeit	Selbststudium	Group size
a) Seminar „Observational Cosmology“	a) 22 h	a) 38 h	Students a) Unlimited

Participation requirements
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.

Content
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.

Teaching forms Seminar

Forms 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 award 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Hendrik Hildebrandt

Other information

Radio Astronomy					
	Credits 2 CP	*Workload* 60 h	**Semester** 1. / 2. Sem.	**Turnus** WiSe	*DURATION* 1 Semester
Courses a) Lecture „Radio Astronomy“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited

Participation requirements
Formal: none
Content: none
Preparation: Introduction to Astrophyiscs 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

Content
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.

Teaching forms Lecture

Forms of examination oral exam 45 min

Requirements for the award of credit points
Passing the oral exam

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Dr. Björn Adebahr

Other information

Research Topics in Heliophysics

	Credits	Workload	Semester	Turnus	DURATION
	2 CP	60 h	from 6th Sem.	WiSe & SoSe	1 Semester

Courses	Kontaktzeit	Selbststudium	Group size
a) Seminar „Research Topics in Heliophysics“	a) 22 h ?	a) 38 h	Students a) Unlimited

Participation requirements
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

Content
In a series of talks by B.Sc., M.Sc., or Ph.D: 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.

Teaching forms Seminar

Forms of examination oral presentation

Requirements for the award of credit points oral presentation

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer PD Dr. Horst Fichtner

Other information

Selected Topics of Astronomy

	Credits	*Workload*	**Semester**	**Turnus**	*DURATION*
	2 CP	60 h	5.,6.,7. Sem	WiSe /SoSe	1 Semester
Courses a) Seminar „Selected Topics of Astronomy“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited

Participation requirements
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 Astrphysics“ 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.)

Content
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 persued 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.

Teaching forms Seminar

Forms of examination Oral presentation and activity in the discussions after the talk

Requirements for the award of credit points
successful presentation of the seminar talk and active participation

Use of the module required Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Dominik Bomans, Prof. Dr. Ralf-Jürgen Dettmar, Prof. Dr. Anna Franckowiak, Prof. Dr. Hendrik Hildebrandt

Other information

Introduction to Space Physics

	Credits	*Workload*	**Semester**	**Turnus**	*DURATION*
	3 CP	90 h	from 5th Sem.	WiSe	1 Semester

Courses	**Kontaktzeit**	**Selbststudium**	**Group size**
a) Lecture „Introduction to Space Physics (Lecture)“ b) Exercise „Introduction to Space Physics (Exercices)“	a) 22 h b) 11 h	a) 57 h	Students a) Unlimited b) 30

Participation requirements

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

Content

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

Teaching forms lectures and exercises

Forms of examination At the beginning of the course the docent defiines 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 award of credit points

Je nach festgelegter Prüfungsform:

Bestehen der Klausur/mündlichen Prüfung oder Erlangen von mindestens 50 % der möglichen Punkte in den wöchentlichen Übungsaufgaben. In diesem Fall ist außerdem eine aktive Beteiligung in der Übung obligatorisch. Die Prüfungsform wird zu Beginn der Veranstaltung festgelegt. Zusätzlich muss das F-Praktikum erfolgreich abgeschlossen werden. Beide Noten gehen mit den CP-gewichtet in die Modulnote ein.

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer PD Dr. Horst Fichtner

Other information

Stars, Wind, Nebulae					
	Credits 2 CP	*Workload* 60 h	**Semester** 4./6. Sem.	**Turnus** SoSe	*DURATION* 1 Semester
Courses a) Lecture „Stars, Wind Nebulae“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited

Participation requirements
Formal: none
Content: none
Preparation: basic know how in astronomy (e.g. Introduction to Astronomy course) neccessary

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.

Content
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.

Teaching forms lecture

Forms of examination possible are an oral exam, a short oral presentation or written essay

Requirements for the award of credit points
active participation and a successfull examination

Use of the module

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Priv. Doz. Dr. Kerstin Weis

Other information

Theoretical Heliophysics					
	Credits 2 CP	*Workload* 60 h	from 5th Sem.	**Turnus** WiSe & SoSe	*DURATION* 1 Semester
Courses a) Seminar „ Theoretical Heliophysics“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited

Participation requirements
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

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

Teaching forms Seminar

Forms of examination The oral presentation (or, in exceptional cases, the term paper) will be evaluated.

Requirements for the award of credit points
Je nach festgelegter Prüfungsform:
Bestehen der Klausur/mündlichen Prüfung oder Erlangen von mindestens 50 % der möglichen Punkte in den wöchentlichen Übungsaufgaben. In diesem Fall ist außerdem eine aktive Beteiligung in der Übung obligatorisch. Die Prüfungsform wird zu Beginn der Veranstaltung festgelegt. Zusätzlich muss das F-Praktikum erfolgreich abgeschlossen werden. Beide Noten gehen mit den CP-gewichtet in die Modulnote ein.

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer PD Dr. Horst Fichtner, Dr. Jens Kleimann

Other information

Stars, Wind, Nebulae					
	Credits 2 CP	*Workload* 60 h	**Semester** 5./7. Sem.	**Turnus** WiSe	*DURATION* 1 Semester
Courses a) Lecture „Variability and Instability in Stars“			**Kontaktzeit** a) 22 h	**Selbststudium** a) 38 h	**Group size** Students a) Unlimited
Participation requirements **Formal:** none **Content:** none **Preparation:** basic know how in astronomy (e.g. Introduction to Astronomy course) neccessary					
Learning outcomes Students will get a broader view on the stellar evolution and stellar varibility and the origin thereof. Mainly from an observational perspective but also theoretical concepts of are introduced and discussed to connect the variabilty to instability processe.					
Content The course concentrates on stellar evolution of stars of all masses. In this context classes and phases in which the stars are variable are presented in more detail. A focus is given on the parameters and processes that initiate the variability and may even influence the stability of a star. The lecture addresses all subjects from an observational point of view but also theoretical models are presented and necessary to explain and describe instabilities. With a possible origin of variability being transits, stellar binaries and even exoplanets are topics in this lecture. Stellar winds and mass transfer between stars are further issues in this context.					
Teaching forms lecture					
Forms of examination possible are an oral exam, a short oral presentation or written essay					
Requirements for the award of credit points active participation and a successfull examination					
Use of the module					
Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade					
Module coordinator/full-time lecturer Priv. Doz. Dr. Kerstin Weis					
Other information					

Biophysics

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

Courses	Contact Hours	Self Study	Group Size
e) Lecture f) Exercises g) Seminar (at least 2 CP) h) 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. e) 44 h f) 44 h g) 22 h h) 35 h	mind. 309 h	Students e) unlimited f) 30 g) 30 h) 2

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module

Importance of the Mark for the Final Mark Weighed 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.

Winter Semester

160821 **Laboratory Biophysics: Molecular Biology of Proteins for Physics Students**

Gerwert, Klaus; Hofmann, Eckhard *Laboratory*

160823 **Laboratory Biophysics: Selected Topics of Molecular Biophysics for Physics Students**
Gerwert, Klaus; Hofmann, Eckhard *Laboratory*

160830 **Biophotonics (Literature Seminar** Gerwert, Klaus; Kötting, Carsten *Seminar*

160835 **Basics and Current Topics of Protein Crystallography (Literature Seminar)**
Hofmann, Eckhard *Lecture*

160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*

Summer Semester:

160801 **Biophysics II (Lecture)** Gerwert, Klaus; Hofmann, Eckhard *Lecture*

160802 **Biophysics II (Exercises)** Gerwert, Klaus; Hofmann, Eckhard *Exercises*

160820 **Biophysics (Seminar)** Gerwert, Klaus; Hofmann, Eckhard *Seminar*

160852 **Computer Simulation of Proteins** Gerwert, Klaus; Hofmann, Eckhard *Seminar*

160855 **Proteincrystallography** Hofmann, Eckhard *Seminar*

160856 **Literature Seminar: Basics and Current Topics of Proteincrystallography**
Hofmann, Eckhard
Seminar

160858 **FTIR in Biophysics (Seminar)** Weis, Kerstin *Seminar*

160859 **Research Laboratory: Selected Topics of molecular Biophysics**
Gerwert, Klaus; Hofmann, Eckhard *Laboratory*

160250 **Fortgeschrittenen-Praktikum für Physikerinnen und Physiker / Advanced Laboratory Course for Physics Students** Reicherz, Gerhard; Krebs, Hermann *Laboratory*

Solid State Physics

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

Courses	Contact Hours	Self Study	Group Size
i) Lecture j) Exercises k) Seminar (at least 2 CP) l) 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. i) 44 h j) 44 h k) 22 h l) 35 h	mind. 309 h	Students i) unlimited j) 30 k) 30 l) 2

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor Prof. Dr. Hägele
Examiners Prof. Dr. Böhmer, Prof. Dr. Drautz, Prof. Dr. Eremin, Prof. Dr. Hägele, Prof. Scherer, Prof. Sulpizi, Prof. Dr. Wieck

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

Winter Semester

160301 **Scientific Methods of Semiconductor Physics** Wieck, Andreas *Lecture*
160302 **Scientific Methods of Semiconductor Physics (Exercises)** Wieck, Andreas *Exercises*
160303 **Semiconductor Physics I** Ludwig, Arne *Lecture*
160304 **Semiconductor Physics I (Exercises)** Ludwig, Arne *Exercises*
160311 **Physics of Quantum Cascade Lasers** Jukam, Nathan *Lecture*
160312 **Physics of Quantum Cascade Lasers (Discussion)** Jukam, Nathan *Seminar / Exercises*
160322 **Selected Topics of Applied Solid State Physics** Wieck, Andreas; Ludwig, Arne *Seminar*
160324 **Journal Club: Applied Solid State Physics** Ludwig, Arne *Seminar / Textlektüre*
160323 **Spintronics and Ultrafast Spectroscopy** Hägele, Daniel *Seminar*
160350 **Quantum Materials** Böhmer, Anna *Seminar*
160325 **Solid State Physics Theory** Eremin, Ilya *Seminar*
160327 **Selected Topics of Solid State Physics Theory** Scherer, Michael *Seminar*
160305 **Compact Course: Practical Exercises in Semiconductor Technology** Ludwig, Arne *Compact Laboratory*
160351 **Semiconductor Band Structures** Ludwig, Arne *Seminar / Lecture*
160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*

Summer Semester

160303 **Introduction to Solid State Physics II** Böhmer, Anna *Lecture*
160304 **Introduction to Solid State Physics II (Exercises)** Böhmer, Anna; Kreyßig, Andreas *Exercises*
160306 **Scientific Methods of Semiconductor Physics** Wieck, Andreas *Lecture*
160307 **Scientific Methods of Semiconductor Physics (Exercises)** Wieck, Andreas *Exercises*
160309 **Semiconductor Physics II: Experiments with Semiconductor Quantum Devices** Ludwig, Arne *Lecture*
160310 **Semiconductor Physics II (Exercises)** Ludwig, Arne *Exercises*
160311 **Advanced Solid State Theory** Eremin, Ilya *Lecture*
160312 **Advanced Solid State Theory (Exercises)** Eremin, Ilya *Exercises*
160319 **Physics of Complex Phase Transitions in Solids** Scherer, Michael; Grünebohm, Anna *Lecture*
160320 **Physics of Complex Phase Transitions in Solids (Exercises)** Scherer, Michael; Grünebohm, Anna *Exercises*
160315 **Introduction to X-ray and Neutron Scattering** Holland-Moritz, Dirk *Lecture*
160510 **Surface Physics and Chemistry** Linsmeier, Christian *Lecture*
160613 **Introduction to Statistics for Astronomers and Physicists** Wright, Angus *Lecture*
160328 **Quantum Optics** Jukam, Nathan *Lecture*
160329 **Quantum Optics (Exercises)** Jukam, Nathan *Exercises*
160322 **Journal Club: Applied solid state physics** Wieck, Andreas; Ludwig, Arne *Seminar*
160323 **Solid State Theory (Seminar)** Scherer, Michael *Seminar*
160327 **Superconductivity (Seminar)** Böhmer, Anna *Seminar*

160358	**Spintronics and Ultrafast Spectroscopy (Seminar)**	Hägele, Daniel	*Seminar*
160326	**Seminar on Quantum Materials (Seminar)**	Böhmer, Anna	*Seminar*
160353	**Selected Topics of Applied Solid State Physics (Seminar)**	Wieck, Andreas; Ludwig, Arne	*Seminar*
160354	**Selected Topics of Solid State Theory (Seminar)**	Eremin, Ilya	*Seminar*
160321	**Semiconductor Band Structures**	Ludwig, Arne	*Seminar*
160250	**Fortgeschrittenen-Laboratory für Physikerinnen und Physiker / Advanced Laboratory Course for Physics Students**	Reicherz, Gerhard; Krebs, Hermann	*Laboratory*

<table>
<tr><td colspan="6">Compact Course: Practical Exercises in Semiconductor Technology</td></tr>
<tr><td></td><td>Credits
4 CP</td><td>Workload
120 h</td><td>Semester
5./6. Sem.</td><td>Turnus
WiSe / SoSe</td><td>DURATION
1 week (plus preparation and a presentation of the results</td></tr>
<tr><td colspan="3">Courses
c) Labcourses: Practical Exercises in Semiconductor Technology</td><td>Contact Hours
c) 40 h</td><td>Self Study
c) 80 h</td><td>Group size
Students
c) 3-5</td></tr>
<tr><td colspan="6">Participation requirements
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.</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td colspan="6">Content
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.</td></tr>
<tr><td colspan="6">Teaching forms Lab course and lecture</td></tr>
<tr><td colspan="6">Forms of examination Oral exam about content and plan how to measure the device (mid term during the week). Presentation after the practical.</td></tr>
<tr><td colspan="6">Requirements for the award of credit points
Successful oral exam and presentation.</td></tr>
<tr><td colspan="6">Use of the module Advanced lab course block in Courses in Physics Major</td></tr>
<tr><td colspan="6">Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade</td></tr>
<tr><td colspan="6">Module coordinator/full-time lecturer Dr. Arne Ludwig</td></tr>
<tr><td colspan="6">Other information</td></tr>
</table>

Journal Club: Applied Solid State Physics

	Credits	Workload	Semester	Turnus	DURATION
	1 CP	30 h	4.-10. Sem.	WiSe / SoSe	1 Semester
Courses d) Seminar			**Kontaktzeit** d) 11 h	**Selbststudium** d) 19 h	**Group size** Students d) Unlimited

Participation requirements
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

Content
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 skepticism (or praise) to the results.

Teaching forms Seminar

Forms of examination Own presentation

Requirements for the award of credit points
Active participation and presentation of a paper.

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Dr. Arne Ludwig

Other information

Physics of Quantum Cascade Lasers

	Credits	Workload	Semester	Turnus	DURATION
	3 CP	90 h	1. / 2. Sem.	WiSe / SoSe	1 Semester
Courses e) Lecture „Physics of Quantum Cascade Lasers” f) Discussion “Physics of Quantum Cascade Lasers”			**Kontaktzeit** e) 22 h f) 11 h	**Selbststudium** e) 57 h	**Group size** Students e) Unlimited

Participation requirements
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

Content

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
Teaching forms Lecture and exercise/discussion session
Forms 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 award 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 Elective
Importance of the final examination for the grade The grade will be determined by the final examination.
Module coordinator/full-time lecturer Dr. Nathan Jukam (email: Nathan.Jukam@rub.de)
Other information

Scientific Methods of Semiconductor Physics

	Credits	Workload	Semester	Turnus	DURATION
	3 CP	90 h	3. - 6. Sem.	WiSe / SoSe	1 Semester

Courses	Kontaktzeit	Selbststudium	Group size
g) Lecture „ Scientific Methods of Semiconductor Physics (Lecture)“ h) Exercise „Scientific Methods of Semiconductor Physics (Exercices)“	g) 22 h h) 11 h	f) 57 h	Students f) Unlimited g) 30

Participation requirements
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

Content
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 analyzer, 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.

Teaching forms Vorlesung, Übungsgruppe

Forms 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 award of credit points
Successful talk / examination

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Andreas Wieck

Other information

Semiconductor Band Structures					
	Credits 1 CP	*Workload* 30 h	**Semester** 1. / 2. Sem.	**Turnus** WiSe / SoSe	*DURATION* 1 Semester
Courses i) Seminar „Semiconductor Band Structures"			**Kontaktzeit** i) 11 h	**Selbststudium** g) 19 h	**Group size** Students h) Unlimited

Participation requirements
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

Content
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.

Teaching forms Seminar, practicals

Forms of examination active participation and presentation of an own simulation project

Requirements for the award of credit points
active participation and presentation

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Dr. Arne Ludwig

Other information

Semiconductor Physics I

	Credits	Workload	Semester	Turnus	DURATION
	4 CP	120 h	5.-9. Sem.	WiSe / SoSe	1 Semester

Courses	**Kontaktzeit**	**Selbststudium**	**Group size**
j) Lecture „Semiconductor Physics I (Lecture)” k) Exercise „Semiconductor Physics I (Exercises)”	j) 33 h k) 11h	h) 76 h	Students i) Unlimited j) 30

Participation requirements
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
- are familiar with semiconductors

Content
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.

Teaching forms Lecture, Exercise

Forms of examination Oral examination at the end of the lecture

Requirements for the award 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Dr. Arne Ludwig

Other information

Solid State Physics Theory					
	Credits 8 CP	*Workload* 240 h	**Semester** 1. / 2. Sem.	**Turnus** WiSe / SoSe	*DURATION* 1 Semester
Courses l) Lecture Course: Advanced Solid State Theory m) Exercise for Advanced Solid State Theory n) Seminar „Solid State Physics Theory"			**Kontaktzeit** l) 44 m) 22 n) 22 h	**Selbststudium** i) 152 h	**Group size** k) Unlimited l) 25 m) 25

Participation requirements
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

Content
Brief description of the subject content:

- 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.

Teaching forms Lecture, Excersize, Seminar

Forms of examination Z 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 award of credit points
JDepending 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 grade for the final grade graded, but does not contribute to the weighted average final grade
Module coordinator/full-time lecturer Prof. Dr. Ilya Eremin
Other information

Spintronics and Ultrafast Spectroscopy					
	Credits 2 CP	**Workload** 60 h	**Semester** 5. - 10. Sem.	**Turnus** WiSe / SoSe	**DURATION** 1 Semester
Courses o) Seminar „Spintronics and Ultrafast Spectroscopy"			**Kontaktzeit** o) 22 h	**Selbststudium** j) 38 h	**Group size** Students n) Unlimite d

Participation requirements
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.
-

Content
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.

Teaching forms Seminar talks by students and instructors

Forms 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 award 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Daniel Hägele

Other information

Solid State Physics Theory

	Credits	Workload	Semester	Turnus	DURATION
	2 CP	60 h	1. Sem.	WiSe	1 Semester
Courses p) Seminar „Solid State Physics Theory"			**Kontaktzeit** p) 22 h	**Selbststudium** k) 38 h	**Group size** o) 25

Participation requirements
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

Content
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,

Teaching forms Seminar

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

Requirements for the award of credit points
JDepending 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 grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Prof. Dr. Ilya Eremin

Other information

Selected Topics of Applied Solid State Physics					
	Credits 2 CP	**Workload** 60 h	**Semester** 3. - 10. Sem.	**Turnus** WiSe / SoSe	**DURATION** 1 Semester
Courses q) Seminar „Selected Topics of Applied Solid State Physics"			**Kontaktzeit** q) 22 h ?	**Selbststudium** l) 38 h ?	**Group size** Students p) Unlimited

Participation requirements
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

Content
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 ultrahigh 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.

Teaching forms: Lecture, talks, discussions

Forms of examination: The student performs a talk of 45 min. plus discussion within the research group

Requirements for the award of credit points: Successful talk with valid discussion

Use of the module Courses in Physics Major

Importance of the grade for the final grade graded, but does not contribute to the weighted average final grade

Module coordinator/full-time lecturer Dr. Arne Ludwig, Prof. Dr. Andreas Wieck

Other information

Nuclear and Particle Physics

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

Courses	Contact Hours	Self Study	Group Size
m) Lecture n) Exercises o) Seminar (at least 2 CP) p) 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. m) 44 h n) 44 h o) 22 h p) 35 h	mind. 309 h	Students m) unlimited n) 30 o) 30 p) 2

Requirements for Participation

Formal: none

Content-Wise: 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.

Utilisation of the Module Compulsory-Elective Module
Importance of the Mark for the Final Mark Weighed according to Credit Points

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

Examiner Prof. Dr. Epelbaum Prof. Dr. Fritsch, Prof. Dr. Heinsius, 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.

Winter Semester

160406 **Symbolic Computation in Mathematica** Krebs, Hermann *Lecture*
160412 **Detectors and Algorithms for Charged Track Reconstruction** Ritman, James *Lecture with integrated Exercises*
160616 **Theoretical Neutrino Astrophysics** Tjus, Julia *Lecture*
160617 **Theoretical Neutrino Astrophysics (Exercises)** Tjus, Julia; Merten, Lukas *Exercises*
160420 **Experimental Methods in Nuclear and Particle Physics** Wiedner, Ulrich *Seminar*
160421 **Detectors for Particle Physics** Wiedner, Ulrich; Heinsius, Fritz-Herbert *Seminar*
160418 **Seminar on Hadron Physics** Fritsch, Miriam *Seminar*
160422 **Selected Topics of Hadron Physics I** Epelbaum, Evgeny; Krebs, Hermann *Seminar*
160429 **Current Topics in the Standard Model and beyond** Epelbaum, Evgeny *Seminar*
160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*

Summer Semester

160401 **Introduction to Nuclear and Particle Physics II** Wiedner, Ulrich *Lecture*
160402 **Introduction to Nuclear and Particle Physics II (Exercices)** Wiedner, Ulrich Exercises
160412 **Particle Detectors for Hadron Physics Experiments** Ritman, James *Lecture*
160413 **Particle Detectors for Hadron Physics Experiments (Excercises)** Ritman, James *Exercises*
160403 **Quantum Field Theory I** Krebs, Hermann *Lecture*
160404 **Quantum Field Theory I (Exercises)** Krebs, Hermann *Exercises*
160411 **Symbolic Computation in Mathematica** Krebs, Hermann *Lecture*
160613 **Introduction to Statistics for Astronomers and Physicists** Wright, Angus *Lecture*
160420 **Experimental Methods in Nuclear and Particle Physics (Seminar)** Wiedner, Ulrich *Seminar*
160421 **Particle Physics Detectors (Seminar)** Wiedner, Ulrich; Heinsius, Fritz-Herbert *Seminar*
160426 **Selected Topics of Hadron Physics II (Seminar)** Epelbaum, Evgeny; Krebs, Hermann *Seminar*
160429 **Effective Field Theories (Seminar)** Epelbaum, Evgeny; Krebs, Hermann; Körber, Christopher *Seminar*
160250 **Fortgeschrittenen-Laboratory für Physikerinnen und Physiker / Advanced Laboratory Course for Physics Students** Reicherz, Gerhard; Krebs, Hermann *Laboratory*

Current Topics in the Standard Model and Beyond

	Credits	Workload	Semester	Cycle	Duration
	2 CP	60 h	1. Sem.	Winter Term	1 Semester
Courses r) Seminar „Current Topics in the Standard Model and Beyond"			**Contact Hours** r) 22 h	**Self-Study** m) 38 h	**Group Size** Students q) 30

Requirements for Participation:
Formal: none
Content-Wise: 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

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Evgeny Epelbaum, Priv Doz. Dr. Hermann Krebs

Further Information

Detectors for Particle Physics					
	Credits 2 CP	**Workload** 60 h	**Semester** 1. Sem.	**Cycle** Winter/Summer Term	**Duration** 1 Semester
Courses s) Seminar „Detectors for Particle Physics“			**Contact Hours** s) 22 h	**Self-Study** n) 38 h	**Group Size** Students r) 30
Requirements for Participation **Formal:** none **Content-Wise:** 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.					
Utilisation of the Module Elective Course					
Importance of the Mark for the Final Mark graded, contribution to the final mark weighed for CP					
Module Supervisor and Instructor Prof. Dr. Ulrich Wiedner, Prof. Dr. Fritz-Herbert Heinsius					
Further Information					

Effective Field Theories					
	Credits 2 CP	**Workload** 60 h	**Semester** 2. Sem.	**Cycle** Summer Term	**Duration** 1 Semester
Courses t) Seminar „Effective Field Theories"			**Contact Hours** t) 22 h	**Self-Study** o) 38 h	**Group Size** Students s) 30

Requirements for Participation:
Formal: none
Content-Wise: 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

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Evgeny Epelbaum, Priv Doz. Dr. Hermann Krebs, Dr. Christopher Körber

Further Information

Experimental Methods in Nuclear and Particle Physics					
	Credits 2 CP	**Workload** 60 h	**Semester** 1. Sem.	**Cycle** Winter/Summer Term	**Duration** 1 Semester
Courses u) Seminar „Experimental Methods in Nuclear and Particle Physics“			**Contact Hours** u) 22 h	**Self-Study** p) 38 h	**Group Size** Students t) 30

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Ulrich Wiedner

Further Information

Introduction to Nuclear and Particle Physics II					
	Credits 4 CP	**Workload** 120 h	**Semester** 7. Sem.	**Cycle** Summer Term	**Duration** 1 Semester
Courses v) Lecture „Introduction to Nuclear and Particle Physics II“ w) Exercises „Introduction to Nuclear and Particle Physics II (Exercises)”			**Contact Hours** v) 22 h w) 22 h	**Self-Study** q) 38 h r) 38 h	**Group Size** Students u) Unlimite d v) 30

Requirements for Participation
Formal: none
Content-Wise: 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.
- Have students 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
Je nach festgelegter Prüfungsform:
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.

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Ulrich Wiedner

Further Information

Selected Topics of Hadron Physics					
	Credits 2 CP	**Workload** 60 h	**Semester** 1. Sem.	**Cycle** Winter and Summer Term	**Duration** 1 Semester
Courses x) Seminar „Selected Topics of Hadron Physics“			**Contact Hours** x) 22 h	**Self-Study** s) 38 h	**Group Size** Students w) 30
Requirements for Participation: **Formal:** none **Content-Wise:** The seminar is aimed at Master students 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					
Utilisation of the Module Elective Course					
Importance of the Mark for the Final Mark graded, contribution to the final mark weighed for CP					
Module Supervisor and Instructor Prof. Dr. Evgeny Epelbaum, Priv. Doz. Dr. Hermann Krebs					
Further Information					

Seminar on Hadron Physics

	Credits	**Workload**	**Semester**	**Cycle**	**Duration**
	2 CP	60 h	1. Sem.	Winter Term	1 Semester
Courses y) Seminar „Seminar on Hadron Physics“			**Contact Hours** y) 22 h	**Self-Study** t) 38 h	**Group Size** Students x) 30

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Miriam Fritsch

Further Information

Plasma Physics

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

Courses	**Contact Hours**	**Self Study**	**Group Size**
q) Lecture r) Exercises s) Seminar (at least 2 CP) t) 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. q) 44 h r) 44 h s) 22 h t) 35 h	mind. 309 h	Students q) unlimited r) 30 s) 30 t) 2

Requirements for Participation
Formal: none
Content-Wise: 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
- Kennen Studierende unterschiedliche Einsatzfelder von Plasmen wie die Wechselwirkung mit biologischen Systemen oder mit den Oberflächen eines Fusionsexperimentes

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.

Utilisation of the Module Compulsory-Elective Module

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

Module Supervisor Prof. Dr. von Keudell

Examiner Prof. Dr. Czarnetzki, Jun-Prof. Dr. Golda, Prof. Dr. Grauer, Jun-Prof. Dr. Innocenti, 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.

Winter Semester
160501 **Introduction to Plasma Physics II** von Keudell, Achim *Lecture*

160502 **Introduction to Plasma Physics II (Exercises)** von Keudell, Achim *Exercises*
160515 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas** Marchuk, Oleksandr *Lecture*
160516 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas (Exercises)** Marchuk, Oleksandr *Exercises*
160618 **Introduction to Space Physics** Fichtner, Horst *Lecture*
160619 **Introduction to Space Physics (Exercises)** Fichtner, Horst *Exercises*
160511 **Confinement Concepts and Advanced Materials for Extreme Environments** Linsmeier, Christian; Unterberg, Bernhard; Coenen, Jan *Lecture*
160521 **Problems of Modern Plasma Physics** Czarnetzki, Uwe; Luggenhölscher, Dirk *Seminar*
160522 **Applied Plasma Physics** von Keudell, Achim; Böke, Marc; Schulz-von der Gathen, Volker; Golda, Judith *Seminar*
160517 **Selected Topics of Plasma Theory** Grauer, Rainer; Dreher, Jürgen *Seminar*
160523 **Compact Course: "Low Temperature Plasma Physics: Basis and Applications" and Master Class "Low Temperature Plasma Physics"** von Keudell, Achim; Böke, Marc; Schulz-von der Gathen, Volker *Compact Seminar*
160510 **Turbulence and Transport in Fusion Plasmas** Püschel, M.J. *Lecture*
160526 **Plasma Kinetics for Experimentalists** Tsankov, Tsanko *Compact Seminar*
160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*

<u>**Summer Semester**</u>

160505 **Plasma Diagnostics** Schulz-von der Gathen, Volker *Lecture*
160506 **Plasma Diagnostics (Exercises)** Schulz-von der Gathen, Volker *Exercises*
160510 **Surface Physics and Chemistry** Linsmeier, Christian *Lecture*
160513 **Introduction to Nuclear Fusion - Plasma- Wall- Interactions and Plasma Edge Physics** Unterberg, Bernhard *Lecture*
160511 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II** Marchuk, Oleksandr *Lecture*
160512 **Modeling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II (Exercises)** Marchuk, Oleksandr *Exercises*
160529 **Introduction to Hydrodynamics** Fichtner, Horst *Lecture*
160530 **Introduction to Hydrodynamics (Exercises)** Fichtner, Horst *Exercises*
160664 **Magnetohydrodynamic Turbulence and Reconnection** Scherer, Klaus *Lecture*
160522 **Problems of Modern Plasma Physics (Seminar)** Tsankov, Tsanko; Luggenhölscher, Dirk *Seminar*
160523 **Applied Plasma Physics (Seminar)** von Keudell, Achim; Golda, Judith; Schulz-von der Gathen, Volker; Böke, Marc *Seminar*
160558 **Seminar on Space Plasma Physics (Seminar)** Innocenti, Maria Elena; Dreher, Jürgen; Dargent, Jérémy *Seminar*
160250 **Advanced Laboratory Course for Physics Students** Krebs, Hermann; Reicherz, Gerhard *Laboratory*

Introduction to Plasma Physics II

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

Courses	Contact Hours	Self-Study	Group Size
z) Lecture „introduction to Plasma Physics II“ (4 CP) aa) Exercises „Introduction to Plasma Physics II (Exercises)“ (1 CP)	z) 22 h aa) 22 h	76 h	Students y) unlimited z) 30

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Elective Course

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

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

Further Information

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

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	2. Sem.	Summer Term	1 Semester

Courses	Contact Hours	Self-Study	Group Size
bb) Lecture „Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II“ cc) Exercises „Modelling of Atomic Populations in the Spectroscopy of Laboratory and Astrophysical Plasmas II (Exercises)“	bb) 22 h cc) 22 h	76 h	Students aa) unlimited bb) 30

Requirements for Participation
Formal: none
Content-Wise: 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.

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Priv. Doz. Dr. Oleksanr Marchuk

Further Information

Plasma Diagnostics

	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	2. Sem.	Summer Term	1 Semester

Courses	Contact Hours	Self-Study	Group Size
dd) Lecture „Plasma Diagnostics“ ee) Exercises „Plasma Diagnostics“	dd) 22 h ee) 22 h	u) 38 h v) 38 h	Students cc) 30

Requirements for Participation
Formal: none
Content-Wise: 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
- Verstehen Studierende die richtige Auswahl einer Diagnostikmethode zu treffen für die Bestimmung von definierten Kenngrößen eines Plasmas

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.

Utilisation of the Module Elective Course

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

Module Supervisor and Instructor Prof. Dr. Volker Schulz-von der Gathen

Further Information

Modul 5.x Compulsory Elective Modules from the Minor Subject

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**:

Minor Subject:	**Modules**
Analytical Chemistry	Methods of Structure Analysis II
Anorganic Chemistry:	Anorganical Chemistry II
	Block Courses Anorganical Chemistry
Biochemistry	Laboratory Biochemical Working Techniques
	Introduction to Biochemistry
	Biochemistry I
Physical Chemistry	Laser Spectroscopy Laboratory
	Rasterforce Microscopy Laboratory
	Biophysical Chemistry I
	Biophysical Chemistry II
	Physical-Chemical Laboratory
	Physical Chemistry II
	Concepts of Spectroscopy and Introduction in Laser Spectroscopy
	Concepts of Spectroscopy II
Technical Chemistry	Technical Chemistry I
	Technical Chemistry II
	Chemical-Technical Laboratory for Physicists
Theoretical Chemistry	Theoretical Chemistry I
	Theoretical Chemistry II
	Theoretical Chemistry III
	Theoretical-Chemical Laboratory for Physicists

From the range of courses from the Faculty of **Geosciences**:

Minor Subject:	**Modules**
Geophysics*	Theoretical Geophysics
	Evaluation and Interpretation of Geophysical Data
	Dynamics of the Earth
	Exploration Goephysics

*we recommend an in-person interview with the student counsellor of geophysics, before taking this minor subject!

From the range of courses from the Faculty of **Electrical Engineering and Information Technology:**

Minor Subject:	**Modules**
Plasmatechnology*	Plasmatechnology I
	Fields, Waves and Particles
Nanoelektronics**	Solid State Electronics
	Nanoelektronics
Microelektronics	VLSI-Design
	Integrated Digital Circuits
Technology of Energy Systems	Introduction to Technology of Energy Systems
	Technology of Regenerative Electric Energy
Communication Technology	Systems of High Frequency Technology
	Digital Processing of Signals
Medical Technology	Ultrasound in Medicin
	Tomographical Imaging in Medicin
	Image Processing in Medicin

*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**:

Minor Subject:	**Modules**
Laser Application Technology*	Laser Technology
	Laser Measurement Technology
	Laser Manufacturing Technology
	Laser Technology in Medicin
Systems and Economics of Energy	Energy Economics
	Energy Conversion Systems
	Regenerative Energy
	Technology of Nuclear Power Plants
	Technology of Nuclear Reactors
	Water Power Plants
Material Sciences	Basic Materials
	Material Sciences I
	Material Sciences II
	Polymere Materials
	Light Metals and Composites
	Electron and X-Ray Diffraction

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

From the range of courses from the Faculty of **Mathematics**:

Minor Subject:	**Modules**
Algebra	Algebra I
	Algebra II (Commutative Algebra and Algebraic Geometry)
	Numbers Theory
	Theory of Representation of Lie-Groups
Geometry/Topology	Curves and Areas
	Differential Geometry I
	Differential Geometry II
	Differential Topology
	Topology I
	Algebraic Topology
Analysis	Functional Analysis
	Function Theory I
	Function Theory II
	Common Differential Equations
	Partial Differential Equations I
	Curves and Areas
	Differential Geometry I
	Differential Geometry II
	Differential Topology
Numerical Mathematics	Numerics I (Numerical Treament of Differential Equations I)
	Numerics II (Numerical Treatment of Differential Equations II)
	Optimisation
Probability Theory and Statistics	Probability Theory I
	Probability Theory II (Stochastical Models)
	Statistics I
	Statistics II
	Mathematical Physics
	Financial Mathematics
	Number Series
Computer Science/Cryptography	Theoretical Computer Science
	Complexity Theory
	Cryptography
	Approximation Theory
	Data Structures
	Databank Systems
	Discrete Mathematics I
	Quantum Algorithms
	Efficient Algorithms
	Cryptanalysis
	Theory of Machine Learning
	Algorithmic Geometry
	Cryptographic Protocols

From the range of courses from the Faculty of **Neuroinformatics**:

Minor Subject:	Modules
Neuroinformatics	Computational Neuroscience: Neural Dynamics
	Computational Neuroscience: Vision and Memory
	Autonomous Robotics (lab course)
	Autonomous Robotics: Action, Perception and Cognition
	Machine Learning: Unsupervised Methods
	Machine Learning: Supervised Methods
	Machine Learning: Evolutionary Algorithms
	Introduction to Deep Learning for Computer Vision (lab course)
	Introduction to Perception
	The Neural Basis of Vision (seminar)
	Computational Cognitive Modeling (seminar)
	Deep Learning Computer Vision

From the range of courses from the **ICAMS**:

Minor Subject:	Modules
Material Sciences	Elements of Microstructure
	Assessment and Description of Materials Properties
	Materials Processing
	Atomistic Simulation Methods
	Advanced Atomistic Simulation Methods
	Interfaces and Surfaces
	Application and Implementation of Electronic Structure Methods
	Phase Field Theory and Application
	Phase Field Theory II
	Programming Concepts in Materials Science
	Quantum Mechanics in Materials Science
	Microstructure and Mechanical Properties
	Continuum Methods in Materials Science
	The Calphad Method
	Multiscale Modeling in Materials Science
	Numerical Simulation of Fracture of Materials
	Lattice Boltzmann Modelling: From Simple Flows to Interface Driven Phenomena
	Modelling of Metal Plasticity in Finite Element Analysis
	Solidification Processing
	Stochastische Prozesse

Computational Physics I

Module 6a	Credits	Workload	Semester	Cycle	Duration
	4 CP	120 h	from 5. Sem.	Winter Term	1 Semester

Courses	Contact Hours	Self Study	Group size
a) Lecture Computational Physics I b) Exercises Computational Physics I	a) 22 h b) 22 h	76 h	Students a) unlimited b) 30

Requirements for Participation
Formal: none
Content-Wise: 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 fort he 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.

Utilisation of the Module Key Competences

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

Module Supervisor and Instructor Jun-Prof. Dr. Innocenti

Further Information

Computational Physics II					
Module 6b	**Credits** 4 CP	**Workload** 120 h	**Semester** From 5. Sem.	**Cycle** Summer Term	**Duration** 1 Semester
Courses c) Lecture Computational Physics II a) Exercises Computational Physics II			**Contact Hours** c) 22 h a) 22 h	**Self Study** 76 h	**Group size** Students c) unlimited a) 30

Requirements for Participation
Formal: none
Content-Wise: 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 fort he 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.

Utilisation of the Module Key Competences

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

Module Supervisor and Instructor Jun-Prof. Dr. Innocenti

Further Information

Scientific English

Module 6c	Credits	Workload	Semester	Cycle	Duration
	5 CP	120 h	ab 4. Sem.	WiSe & SoSe	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	Students a) 30 b) unlimited

Requirements for Participation
Formal: Proof of language aptitude through an entrance test (cf. www.zfa.rub.de)
Content-Wise: 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

Utilisation of the Module Key Competences

Importance of the Mark for the Final Mark Weighed 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++, Phython, 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 **RUBION**:

Module:	**Workload/ Credits**	**Semester:**	**Frequency of Offering:**	**Duration:**
Foundational Course in Radiation Protection S4.1	150 h/5 CP		s. RUBION	Block Course

From the catalogue of the **Academic Writing Centre**:

Module:	**Workload/ Credits**	**Semester:**	**Frequency of Offering:**	**Duration:**
Intensive Module Theses in Science and Engineering A or B	5 CP		s. SCHREIBZENTRUM	1 Semester

From the catalogue of the faculty of **Economic Sciences**:

Modules (key competences) from economic sciences

Corporate Finance I: Finanzierung & Investition
Corporate Finance II: Finanzielles Risikomanagement
Corporate Finance III: Kapitalmarkttheorie
Start -Up I: Grundlagen der Existenzgründung
Start-Up II: Coaching-Workshop für Existenzgründer
Start-Up III: Grundlagen der Businessplanerstellung

Leading a Project

Module 7	Credits	Workload	Semester	Cycle	Duration
	5 CP	150 h	ab 1. Sem.	Summer Term	1 Semester

Courses	Contact Hours	Self Study	Group Size
a) Seminar Project Management b) Practical exercises Project Management	a) 50 h b) 50 h	50 h	Students a) 30 b) 30

Requirements for Participation
Formal: none
Content-Wise: 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 %)

Utilisation oft he Module Mandatory Module

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

Module Supervisor and Instructor Lecturers oft he 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 Metheods and Planning of the Project

Module 8	Credits 15 CP	Workload 450 h	Semester 3. Sem.	Cycle WiSe & SoSe	Duration 1 Semester
Courses a) Practical exercises b) Seminar			**Contact Hours** a) 320 h b) 30 h	**Self Study** 100 h	**Group Size** Students 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-Wise: none
Preparation: none

Learning Outcomes
After successfully completing the module, the students
- re 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

Utilisation oft he Module Mandatory Module

Importance of the Mark for the Final Mark Weighed 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.	WiSe & SoSe	2 Semesters
Courses			**Contact Hours**	**Self Study**	**Group Size**
a) Seminar A b) Seminar B			a) 100 h b) 30 h	320 h	Students a) 30 b) 30

Requirements for Participation
Formal: proof of completion of the module “Knowledge of Methods and Planning a Project”
Content-Wise: 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

Utilisation oft he Module Mandatory Module

Importance of the Mark for the Final Mark Weighed 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 30 CP	Workload 900 h	Semester 3. & 4. Sem.	Cycle WiSe & SoSe	Duration 2 Semester
Courses Thesis			**Contact Hours** 720 h	**Self Study** 180 h	**Group Size** 1

Requirements for Participation
Formal: proof of completion of the module “Knowledge of Methods and Planning a Project”
Content-Wise: 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

Utilisation of the Module Mandatory Module

Importance of the Mark for the Final Mark Weighed 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.

You can find the list of current topics for Master's theses in our Moodle course "Physikstudium-Info"

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.

Studienplan Master of Science Physics

Ruhr-Universität Bochum
Physik und Astronomie
from matter to materials

Master of Science	Semester	Experimentalphysik	Theoretische Physik	Schwerpunkt	Nebenfach	Schlüsselkompetenzen	Masterarbeit
		9-18 CP	6-15 CP	15-25 CP	5-18 CP	5-15 CP	60 CP
Vertiefungsphase	1	Wahlpflichtmodule aus der Experimentalphysik (z.B. Astro/Bio/FK/KT/Plasma) 1 VL + 3 FP	Wahlpflichtmodule aus der Theoretischen Physik (z.B. ART/Statistik/QM II)	Spezialvorlesung/Seminar/Praktikum (Astro/Bio/FK/KT/Plasma) Pflicht: 5 FP, 1 Seminar (mündl. Prüfung 2 CP)	Module aus anderen Fakultäten	z.B. C++ oder Scientific Writing 0-10 CP	
	2	Wahlpflichtmodule aus der Experimentalphysik (z.B. Astro/Bio/FK/KT/Plasma) 1 VL + 3 FP	Wahlpflichtmodule aus der Theoretischen Physik (z.B. Astro/FK/Plasma) 1 VL + 3 FP		Module aus anderen Fakultäten	Projektleitung 5 CP	
Forschungsphase	3						Methodenkenntnis und Projektplanung 15 CP; Projektseminar zur MA-Arbeit 15 CP
	4						MA-Arbeit 30 CP

Legende

- Module Experimentalphysik
- Module Theoretische Physik
- Module Schwerpunkt
- Module Nebenfach
- Schlüsselkompetenz (Wahl)
- Schlüsselkompetenz (Pflicht)
- Abschlussarbeit und vorbereitende Module

Stand: 01.09.2022