Ruprecht-Karls-University Heidelberg
Department of Physics and Astronomy

Master of Science (M.Sc.)

Physics

Description of the course modules.

Version 2018/V8

Versions:

Version 2014/ko	Outcome oriented description of the objectives of the course modules.
Version 2016/V1	Renaming Project Module Condensed definition MVMod re-visited
Version 2017/V4	Spelling correction
Version 2017/V5	Changes Cosmology Module
Version 2017/V6	Changes Preambel
Version 2018/V7	Changes Table 2.1: Core courses
Version 2018/V8	Changes Module MKEP2, MKEP3, MVSEM, MVRS MKTP2, MPTP3

Name of university	Heidelberg University
Name of department	Physics & Astronomy
Name of subject	Physics
Name of degree course*	Master of Science (Physics)
Fomat of studies	Full time
Type of degree course*	Consecutive
Date of version	February 12th, 2018
Prescribed period of study	Two years, i.e. four semesters
Establishment of degree course	Juli 25th, 2008
Subject-specific assignment	Physics
Location	Heidelberg
Total number of creditpoints	One hundred twenty
University places	Unlimited
Fees	None
Target group	Bachlor of science degree holders having majored in physics

Qualification Goals in Teaching of Heidelberg University

Following its mission statement and its charter Heidelberg University pursues in its degree courses disciplinary, interdisciplinary and professional goals in the comprehensive academic education and for the subsequent professional career of its students. The resulting profile of competence is to be included in the module manuals of all degree programs and will be implemented in all specific qualification goals as well as in the curricula and modules of the individual degree programs:

- development of disciplinary competence with specific orientation towards research;
- development of transdisciplinary competence for dialogue;
- buildup of practical problem solving competence;
- development of personal and social competence;
- promotion of the willingness to take on social responsibility on the basis of the acquired competences.

Disciplinary and interdisciplinary goals of qualification of the master of science physics degree programme

The master of science physics degree programme aims at expanding proficiency in physics towards topics relevant in cutting-edge research at Heidelberg University. Graduates of the master programme are able to apply methods of physics, advance these methods independently as well as implement them efficiently. Using methods and techniques of physics to solve practical applications represents a major part of the qualification. Preparation of a master thesis fosters to a high degree the ability to conduct independent research, problem analysis and solving as well as the organisation of work.

Graduates of the master of science physics degree programme are able to communicate scientifically both orally and in writing. They are capable of compiling scientific texts as well as presenting reports, products and ideas publicly. They are apt to acquire new knowledge and skills on their own and are able to manage their learning process actively as well as to shape the advancement of their learning curve independently. They master the collection of relevant information from different sources and are capable of analyzing, construing, assessing, integrating and differentiating them as well as taking decisions and standpoints based on them.

Graduates of the master of science physics degree programme are able to formulate their standpoint, their subject-related position towards and their solution to problems in physics. In addition, they are capable of outlining problems, solutions and the underlying information on a concurrent level for both scientists and pedestrians. Moreover, they are trained to lead a scientific argument and to defend their findings in the area of their specialization in front of an academic audience.

Graduates master to operate successfully both professionally and in the interdisciplinary and intercultural context of a team, and are well-equipped to take important responsibilities. They are able to lead and guide others, as well as to mobilise and motivate their peers. They are trained in the application of scientific knowledge and are sensitive to and open towards the interaction with other cultures and genders aiming perpetually at the maximization of the team’s performance.

Contents

1. Structure of the curriculum

The first two semesters (first year, specialization phase) of the master programme serve to deepend and extend the education of the student through lectures, seminars and other such schooling events. The second or final year of the master programme is conceived of as a research phase, in which the master's students independently perform research and gain the capabilities of developing new ideas.

In the following chapters, we list the core, specialization and elective (options) courses on offer for the master degree and indicate the number of obligatory credit points (CP) assigned to each of these sectors. One CP corresponds to a work load of 30 hours. During the first year, obligatory core courses totalling 16 CP must be successfully attended; in addition, a further 24 to 28 CP must be gained through successfully completing specialization courses, and 16 to 20 CP must be gained through the successful completion of optional courses (further called Options), i.e. courses that are either close to the field of specialization or of an interdisciplinary nature, and which may be chosen from the wide range of courses on offer by the Department of Physics and Astronomy. The total sum of CP gained during the specialization phase should add-up to 60 CP.

The 24 to 28 CP gained through specialization courses should comprise a "Compulsory Advanced Seminar" on an advanced subject (possibly in the field of specialization) with 6 CP and the "Specialization Module". The Specialization Module can be freely composed by the students. It should comprise courses (lectures and tutorials) in a single field of specialization of 12 to 16 CP. The courses should be chosen from the specialization programme listed in Section 3. Courses from the core physics programme (see Section 2) are also eligible if they are not already used to fulfil the core course obligation. The Specialization Module will be completed and graded by an oral examination. The comprehensive preparation of the oral examination contributes with further 6 CP to the total credit points (18 to 22 CP) of the Specialization Module.

In the second year or research phase of the master degree, the course points are made up of two compulsory modules, "Scientific Specialization" and "Methods and Project Planning", each being assigned 15 CP, as well as the master thesis itself, which counts 30 CP.

During the two years master course a master student is required to successfully pass course modules equivalent to a total of 120 credit points. Further details, in particular on the grading of the modules are laid down by the rules and regulations for master students (Prüfungsordnung).

In Table I, an overview is given of the master programme and the credit points assigned to each course category. The actual modules for different fields of specialization are summarized in the chapters following this. Note that within the core, specialization and options sectors, students have a wide choice available for selecting their modules. As an aid to constructing a sensible and coherent combination, we give examples of model study plans in Chapters 3 and 6 for suitable course programmes.

Table 1.1: Overview of the master degree programme

Module	Code	CP
Specialization Phase		
Core courses (mandatory)		
(1) Theoretical Statistical Physics	MKTP1	8
(2) Theoretical Astrophysics	MKTP2	8
(3) General Relativity	MKTP3	8
(4) Quantum Field Theory	MKTP4	8
(5) Cosmology	MKTP5	8
(6) Particle Physics	MKEP1	8
(7) Condensed Matter Physics	MKEP2	8
(8) Advanced Atomic, Molecular and Optical Physics	MKEP3	8
(9) Environmental Physics	MKEP4	8
(10) Astronomical Techniques	MKEP5	8
Total number of credit points – core courses		16
Specialization in physics (mandatory)		
Mandatory seminar	MVSem	6
Specialization module:	MVMod	18 - 22
Lectures, tutorials,, seminars (12...16 CP)		
Oral examination (6 CP)		
Total number of credit points – specialization		24 - 28
Options Courses within physics or in neighbouring fields or interdisciplinary courses	Section 3	16 - 20
Total number of credit points – options		16 - 20
Total number of credit points – specialization phase		60
Research phase		
Mandatory module “Field of Specialization”	MFS	15
Mandatory module “Methods and Project Planning”	MFP	15
Master Thesis	MFA	30
Total number of credit points – research phase		60
Total number of credit points – Master of Science		120

2. Core courses in physics

During the first two semesters of the master programme two obligatory core courses totalling 16 CP must be attended and successfully passed. The two courses must be chosen from the list of core courses given in Table 2.1. In case one or several courses have already been passed and used to fulfil the point requirement for the bachelor programme the student is required to choose different courses. Core courses of a given field of specialization can also be selected as part of the Specialization Module.

Note that detailed information on the content of these courses is given in the remainder of this chapter. (Further details can be found in the rules and regulations for the master degree in physics.)

Table 2.1: Core courses

Module code	Module	LP/CP	Term
MKTP1	Theoretical Statistical Physics	8	WiSe
MKTP2	Theoretical Astrophysics	8	WiSe
MKTP3	General Relativity	8	SuSe
MKTP4	Quantum Field Theory	8	WiSe
MKTP5	Cosmology	8	WiSe
MKEP1	Particle Physics	8	WiSe
MKEP2	Condensed Matter Physics	8	SuSe
MKEP3	Advanced Atomic, Molecular and Optical Physics	8	WiSe
MKEP4	Environmental Physics	8	WiSe/SuSe
MKEP5	Astronomical Techniques	8	SuSe

Code: MKTP1	Course title: Theoretical Statistical Physics
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Foundations of statistics, information, entropy • Statistical description of physical systems • Ensembles, density of states • Irreversibility • State variables, ideal and real gases, thermodynamic potentials, the fundamental laws of thermodynamics, • Material constants, equilibrium of phases and chemical equilibrium, law of mass action, ideal solutions • Fermi- and Bose-statistics, ideal quantum gases • Phase transitions, critical phenomena (Ising model) • Transport theory (linear response, transport equations, master equation, Boltzmann equation, diffusion) • The theory of the solid state as an example for a non-relativistic field theory • Applications, for example specific heat of solids, thermodynamics of the early universe etc.
Objectives	After completing the course the students • have a thorough knowledge and understanding of the laws of thermodynamics and of the description of ensembles in the framework of classical and quantum statistics and there applications to phase transitions, condensed matter, plasma and astrophysics • have acquired the necessary mathematical knowledge and competence for an in-depth understanding of this research field, • have advanced competence in the fields of theoretical physics covered by this course, i.e. the ability to analyze physical phenomena using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to interpret the solutions physically and communicate them efficiently, • are able to broaden their knowledge and competence in this field of theoretical physics on their own by a systematical study of the literature.
Module parts and teachings methods	• Lecture on “Statistical Physics” (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• Content of PEP3, PTP4 • Announced by lecturer

Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination.
Term	Winter semester
Duration	1 semester

Code: MKTP2	Course title: Theoretical Astrophysics
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Radiative processes: Macroscopic radiation measurements; emission, absorption and scattering, radiative transfer; Bremsstrahlung and synchrotron radiation; ionization and recombination; spectra • Hydrodynamics: Basics and equations of motion; ideal and viscous fluids and currents; sound waves, supersonic currents and shock waves; instabilities, convection and turbulence • Plasma physics: Basics of collision-less plasmas; dielectric tensor; dispersion relation, longitudinal waves and Landau damping; magneto-hydrodynamic equations; waves in magnetized plasmas; hydrodynamic waves • Stellar dynamics: Relaxation; Jeans equations and Jeans theorem; tensor-virial theorem; equilibrium and stability of self-gravitating systems; dynamical friction; Fokker-Planck approximation
Objectives	In this course, students gain a firm understanding of the theoretical concepts of astrophysics, together with their assumptions and limitations. Upon completion of the lecture they are able to apply this knowledge to a wide range of different areas of modern astrophysics and can solve complex problems in this field. The students are familiar with concepts from different areas of theoretical physics relevant for astrophysics and they can apply mathematical techniques for solving questions arising in astrophysical situations.
Module parts and teachings methods	• Lecture on Theoretical Astrophysics (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• content of PTP1, PTP2, PTP3, PTP4, WPAstro/MVAstro0 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination
Term	Winter semester
Duration	1 semester

Code: MKTP3	**Course title: General Relativity**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Manifolds • Geodetics, curvature, Einstein-Hilbert action • Einstein equations • Cosmology • Differential forms in General Relativity • The Schwarzschild solution • Schwarzschild black holes • More on black holes (Penrose diagrams, charged and rotating black holes) • Unruh effect and hawking radiation
Objectives	After completing the course the students • have a thorough knowledge and understanding of Einstein's theory of General Relativity including the necessary tools from differential geometry and applications such as black holes, gravitational radiation and cosmology, • have acquired the necessary mathematical tools from differential geometry, are trained in their application to physical situations with strong gravity and are familiar with their interpretation, • have advanced competence in the fields of theoretical physics covered by this course, i.e. the ability to analyze physical phenomena using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to interpret the solutions physically and communicate them efficiently, • are able to broaden their knowledge and competence in this field of theoretical physics on their own by a systematical study of the literature.
Module parts and teachings methods	• Lecture on "General Relativity" (4 hours/week) • Exercise with homework (2 hours/week)
Prerequisites	
Necessary and useful knowledge	• content of PTP1, PTP2, PTP3, PTP4 • announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination

Term	Summer semester
Duration	1 semester

Code: MKTP4	Course title: Quantum Field Theory (QFT1)
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Quantizing covariant field equations • Interacting fields, S-matrix, LSZ • Invariant Perturbation Theory • Feynman rules, cross sections • Path integral formulation of QFT • Renormalization of scalar theories • Lorentz group • Dirac equation • Feynman rules • Path integral of fermions
Objectives	After completing the course the students • have a thorough knowledge and understanding of relativistic field equations and the theory of free quantum fields, • will be able to use Feynman rules to calculate on the tree level scattering amplitudes and cross sections for Φ4-theory and for simple reactions in QED, • have acquired the necessary mathematical knowledge and competence for an in-depth understanding of this research field, • have advanced competence in the fields of theoretical physics covered by this course, i.e. the ability to analyze physical phenomena using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to interpret the solutions physically and communicate them efficiently, • are able to broaden their knowledge and competence in this field of theoretical physics on their own by a systematical study of the literature.
Module parts and teachings methods	• Lecture on “Quantum Field Theory 1” (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP3, PTP4, MKTP1 • announced by lecturer
Specialities	exercises with homework.
Usability	

Form of testing and examination	usually a 2-3 hours written examination
Term	Winter semester
Duration	1 semester

Code: MKTP5	**Course title: Cosmology**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Homogeneous and isotropic cosmology: Friedmann-Lemaître models; characteristic scales and horizons; geometry, redshift and dynamics; parameters, distance measures and age of the Universe, dark energy models, alternative gravitational theories; • Thermal history: adiabatic evolution; non-relativistic and relativistic gases; photon and neutrino backgrounds, relics, phase transitions, thermodynamic equilibrium and freeze-out, baryogenesis, nucleosynthesis; • Cosmological inflation: problems of FLRW-models, solution by inflation, slow-roll conditions; single-field inflation; creation of structures, scalar and tensor perturbations, spectrum, non-Gaussianities, gauge choice; • Dark matter: arguments for dark matter, relation to particle physics, dark matter candidates; • Cosmic microwave background: theory of temperature and polarisation fluctuations, typical amplitudes and scales; secondary anisotropies; observations and conclusions, gravitational waves; • Statistics of large-scale structures: Gaussian random fields, correlation functions, power spectra and polyspectra, their estimation and cosmic variance; projections and Limber's equation, deviations from Gaussianity, perturbation theory and structure formation, influence of baryons and Jeans' criterion; approaches to non-linearity, velocity fields; • Bound structures: spherical-collapse model, halo statistics; internal structure of haloes, galaxy clusters and galaxies, cosmological surveys; • Gravitational lensing: weak and strong gravitational lensing; lensing of individual objects and time delays, correlation functions and measurements; weak lensing of the CMB;
Objectives	In this course, students gain a firm understanding of the theoretical concepts of cosmology, together with their assumptions and limitations. Upon completion of the lecture they are able to apply this knowledge to a wide range of different areas of modern astrophysics and can solve complex problems in this field. They understand the links between different areas of theoretical physics, in particular in view of common techniques and methods.
Module parts and teachings methods	• Lecture on Cosmology (4 hours/week) • Exercise with homework (2 hours/week)

Necessary and useful knowledge	Necessary/useful Knowledge: Content of PTP1, PTP2, PTP3, PTP4, WPAstro and General Relativity
Specialities	exercises with homework
Usability	
Form of testing and examination	usually a 2-3 hours written examination
Term	Winter semester
Duration	1 semester

Code: MKEP1	**Course title: Particle Physics**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	The focus of the lecture are the experimental tests of the building blocks of matter and their fundamental interactions: • Test of QED in electron-positron annihilation • Probing the structure of the nucleon • Strong interaction • Weak interaction: charged and neutral currents • Electro-weak unification: The Standard Model • Flavour oscillations and CP violation • Physics beyond the Standard Model • Particle physics and cosmology
Objectives	After completing this course students • have acquired basic knowledge about the building blocks of matter, the fundamental interactions and open questions in particle physics, • can describe experimental methods to probe the structure of matter and analyse experimental data, • are able to perform simple calculations to describe particle interactions.
Module parts and teachings methods	• Introductory Lecture on Experimental Particle Physics (4 hours/week) • Exercises with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP4, PEP5, PTP4 • announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination
Term	Winter semester
Duration	1 semester

Code: MKEP2	**Course title: Condensed Matter Physics**
Type	Lecture with exercises, seminar
Language	English
Credit points	8
Workload	240 h
Contents	• Structure of solids in real and reciprocal space • Lattice dynamics and phonon band structure • Thermal properties of insulators • Electronic properties of metals and semiconductors: band structure and transport • Optical properties from microwaves to UV • Magnetism • Superconductivity • Defects, surfaces, disorder (each chapter includes experimental basics)
Objectives	After completing the course the students • have gained a thorough understanding of the fundamentals of condensed matter physics and can apply concepts of many-particle quantum mechanics to pose and solve relevant problems. • will be able to describe the priciples of formation of solids and can probose appropriate experimental methods to study structural properties. They are familiar with and can apply the concept of reciprocal space. • they can apply fundamental electronic models to explain and predict properties of crystalline materials as metals, semiconductors, and insulators. • they can ascribe optical, magnetic properties of matter to electronic and structure degrees of freedom. • they can describe and theoretically explain fundamental propterties of superconductivity • they are able to choose appropriate experimental methods for probing structural, optical, magnetic, and electronic properties of condensed matter and can analyse the experimental results.
Module parts and teachings methods	• Lecture on Condensed Matter Physics (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP1-PEP5 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination.

Term	Winter semester/Summer semester
Duration	1 semester

Code: MKEP3	Course title: Advanced Atomic, Molecular and Optical Physics
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Review of basic quantum mechanics • Dirac equation and relativistic corrections • Quantization of the electromagnetic field and consequences • Many-electron atoms • Molecular structure • Interaction with electromagnetic fields • Time-dependent processes • Scattering and collisions • Quantum statistics and quantum gases • AMO Physics in Heidelberg (with laboratory visits)
Objectives	After completing this course the students will be able to • describe the experimental and theoretical concepts of modern atomic, molecular and optical physics, • analyse standard experimental approaches of modern atomic, molecular and optical physics, • design simple experimental set-ups in modern atomic, molecular and optical physics, • apply the theoretical methods to simple practical examples.
Module parts and teachings methods	• Lecture (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	PEP1-PEP5, PTP1-PTP4
Specialities	Exercises with homework.
Usability	
Form of testing and examination	Written examination (2 hours).
Term	Winter semester
Duration	1 semester

Code: MKEP4	**Course title: Environmental Physics**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Molecular basis of transport processes Einstein's approach to Brownian, Fokker-Planck transport of scalar and vectorial quantities, macroscopic properties • Fluid dynamics conservation laws (mass, momentum, angular momentum, energy), dimensionless numbers, approximations, turbulence • Modelling concepts models, ODE- and PDE-formulations, finite automata, fundamentals of numerical solutions • Fundamentals of reaction kinetics mass action law, reaction dynamics, chemical systems • System Earth and its workings compartments (atmosphere, oceans, land, cryosphere), fluxes and cycles (energy, water, carbon), the climate machine
Objectives	Students achieve a fundamental understanding of the key physical processes and interactions in the Earth surface system and its compartments, as well as of the human impact on these systems and the related societal implications. They are able to solve basic problems of environmental physics and interpret the results in the context of fundamental questions regarding the physics of the earth surface environments and the methodologies to observe and study those.
Module parts and teachings methods	• Lecture on "Environmental Physics" (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP1-PEP3 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	usually a 2-3 hours written examination
Term	Winter semester/Summer semester
Duration	1 semester

Code: MKEP5	Course title: Astronomical Techniques
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Optical telescopes: optics and characteristic parameters, telescope types, diffraction, resolution, aberrations and corrections, applications • Optical detectors: detector types, semiconductors and CCDs, quantum efficiency, readout, noise sources, multi-chip cameras, applications • Imaging: techniques, photometry, data reduction and characterisation, signal-to-noise • Atmospheric effects and corrections: extinction, turbulence, seeing, active and adaptive optics, laser guide stars, applications • Spectroscopy: types of spectrographs and spectrometers, dispersive elements, integral field units, data reduction and characterisation, applications • Infrared astronomy: detectors and techniques, sources, applications • Radio astronomy: detectors and instrumentation, synthesis techniques, types of radiation and sources, applications • Astronomical interferometry: wavelength regimes, instrumentation, applications • X-ray and gamma-ray astronomy: detectors and instrumentation, types of radiation and sources, applications • Astroparticle physics: neutrino and Cherenkov detectors, sources and acceleration mechanisms of neutrinos and cosmic rays, applications • Gravitational-wave astronomy: detection, sources, applications. • In-situ exploration and remote sensing.
Objectives	After completing this course, the students have firm insight into the concepts, technologies, and the underlying physical principles and limitations of modern observational techniques along with scientific applications. They have knowledge of basic detector designs for different types of radiation and particles. They understand the environmental influence on astronomical observations. They are able to select and judge the adequate observational technique for studying an astronomical object of interest.
Module parts and teachings methods	• Lecture on “Astronomical Techniques” (4 hours/week) • Exercises with homework (2 hours / week)
Necessary and useful knowledge	• prerequisites: knowledge of the introductory astronomy lectures (MVAstro0 or WPAstro); basic knowledge of electromagnetic radiation • recommended literature to be announced by the lecturer

Specialities	Credit points can be acquired either for MVAstro1 or for MKEP5, but not for both modules. The Laboratory Course Astrophysics is recommended as complementary to the MKEP5 module.
Usability	
Form of testing and examination	usually a 2-3 hours written examination
Term	Summer semester
Duration	1 semester

3. Specialization courses in physics

The specialization part of the master programme in physics comprises the mandatory Advanced Seminar (MVSem) with 6 CP and the mandatory Specialization Module (MVMod). The latter combines sub-modules (lectures and tutorials) totalling between 12 and 16 CP, and is completed by an oral examination with 6 CP. The sub-modules of the Specialization module should be selected from a single specialization field in physics. They may be chosen from the courses listed in this Section, but may also be selected from the list of core courses given in Section 2. The latter is only possible in case that the selected courses are not used to fulfil the core physics requirement of Section 2 and that the courses were not used to fulfil the bachelor requirements.

Note that the modules listed here can also be selected as courses for the Options discussed in Section 4.

While master students are free to make their course choices as they wish, the Department of Physics and Astronomy does recommend that students choose in accordance with the suggested model study plans. These are intended to enable students to construct a coherent and sensible plan for their studies.

In what follows in this Section, the courses are listed according to their respective research fields. Courses that are offered by the Department on a regular basis have been assigned a module code, such as MVAstro1, and are listed in tables at the beginning of each research field description. Note, however, that not all modules will be offered on a regular basis. In particular, the specialization courses, seminars and journal clubs may vary from semester to semester and field to field. Modules offered on an irregular basis are thus summarized in Table 3 and are assigned unspecific, generic module codes, MVMod, MVSem, MVSpec, MVRS and MVJC. The topics that may be offered are listed in the specific paragraphs devoted to these fields; the Department of Physics and Astronomy does guarantee that in every semester a sufficient number of specialization courses, seminars and journal clubs will be offered. Specific details can be found in the departmental course listing that is made available each semester. The number of credit points assigned to specialization courses (MVSpec) can be seen in tables named "specialised lectures and seminars" found at the beginning of each research field section.

Table 3: Specialization courses, seminars and journal clubs

Module code	Module	LP/CP	Term
MVSem	Mandatory Advanced Seminar	6	WiSe/SuSe
MVMod	Specialization module: Specialization courses (12 - 16 CP) Oral examination (6 CP)	18 - 22	WiSe/SuSe
MVSpec	Advanced Lecture on Special topic	2-8	WiSe/SuSe
MVRS	Research Seminar on special topic (optional)	2	WiSe/SuSe
MVJC	Journal Club	2	WiSe/SuSe
MProj	Project Practical	4-12	WiSe/SuSe

Code: MVSem	**Course title: Mandatory Advanced Seminar**
Type	Mandatory Seminar
Language	English
Credit points	6
Workload	180 h
Contents	• Preparation and presentation of an advanced topic in experimental or theoretical physics or another physics related area; during the seminar about 12 talks on a specific research field are given and actively discussed by all course participants. • Beside the oral presentation of the research topic also is write-up of the presented talk is required.
Objectives	After completion of this module, the student can describe the intentions and difficulties of modern research in physics or another physics related area. The student can handle modern literature and can extract information from present-day physics publications.
Module parts and teachings methods	• Advanced Seminar (mandatory)
Prerequisites	
Necessary and useful knowledge	• general knowledge about the research field discussed. • to be announced by lecturer
Specialities	-
Usability	
Form of testing and examination	presentation and write-up as well as participation in discussions.
Term	Winter semester/Summer semester
Duration	1 semester

Code: MVMod	**Course title: Specialization Module**
Type	Lectures and tutorials
Language	English
Credit points	18 - 22
Workload	540-660 h
Contents	Special topics on a particular research area. The exact modules can be chosen freely among the lecture courses marked by "MV*" in the course booklet by the student. It is recommended to follow the selection of the corresponding model study plan. If a student has successfully passed more than two core modules (marked my "MK*" in the course booklet), those core modules that will not be credited to the core section of the study plan may be chosen as well.
Objectives	After completion of the Specialization Module, the student has gained advanced knowledge about a specific research field. The student also is able to understand the content of the individual modules in a larger context, and he or she is able to transfer some of this knowledge to other fields of physics.
Module parts and teachings methods	• Several modules from a single specialization field selected by the student and totalling between 12 and 16 CP. The courses can be selected from the list of specialization courses in Section 3. Core physics courses are also eligible, if they have not already been credited to the core section.
Necessary and useful knowledge	• general knowledge about the research field discussed • to be announced by lecturer
Specialities	-
Usability	
Form of testing and examination	The single sub-modules have to be passed individually. The complete module is graded by the oral examination after all sub-modules have been passed.
Term	Winter semester/Summer semester
Duration	2 semester

Code: MVSpec	**Course title: Advanced Lecture on Special Topic**
Type	Lecture
Language	English
Credit points	2 - 8
Workload	60 - 240 h
Contents	Special topics on a particular research area
Objectives	The student has gained advanced knowledge about a specific research field.
Module parts and teachings methods	Advanced Lecture on Special Topic
Necessary and useful knowledge	• general knowledge about the research field discussed. • to be announced by lecturer
Specialities	
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester/Summer semester
Duration	1 semester

Code: MVRS	Course title: Research Seminar (optional)
Type	Seminar
Language	English
Credit points	2
Workload	60 h
Contents	Preparation and presentation of an advanced topic in experimental or theoretical physics or another physics related area; during the seminar about 12 talks on a specific research field are given and actively discussed by all course participants.
Objectives	The student has gained a deeper understanding of the intentions and difficulties of modern research in physics or another physics related area. The student is able to pose intentions and difficulties of modern research in physics or another physics related area. He or she has learned how to handle modern literature and how to extract information from present-day physics publications.
Module parts and teachings methods	Advanced Seminar
Prerequisites	
Necessary and useful knowledge	• general knowledge about the research field discussed • to be announced by lecturer
Specialities	-
Usability	
Form of testing and examination	presentations and participation in discussions.
Term	Winter semester/Summer semester
Duration	1 semester

Code: MVJC	**Course title: Journal Club**
Type	Seminar
Language	English
Credit points	2
Workload	60 h
Contents	• Joint reading of current publications on a specific research area in physics or another physics related area. Papers are introduced by participants of the course who also lead the discussion • Short introductory lectures on the different topics discussed may be given by the lecturer(s) of the course.
Objectives	The student has achieved a deeper understanding of the intentions and difficulties of modern research in physics or another physics related area, and has trained how to handle modern literature and how to extract information from present-day physics publications.
Module parts and teachings methods	Journal Club
Necessary and useful knowledge	• general knowledge about the research field discussed. • to be announced by lecturer
Specialities	
Usability	
Form of testing and examination	presentation and participation in discussions.
Term	Winter semester/Summer semester
Duration	1 semester

Code: MProj	**Course title: Project Practical**
Type	Practice Course
Language	English
Credit points	4 - 12
Workload	120 h - 360 h
Contents	• Project work on a limited topic or collaboration in ongoing research. • The student will collaborate with members of a research group and pursue a well-defined project, which can include literature research, experimental work, or theoretical studies.
Objectives	After completion of this module • the student become exposed to scientific conduct, • he or she has become acquainted with a current research topic, • he or she has acquired technical skills that will be useful for the later research phase.
Module parts and teachings methods	• Project practical in a research group. Upon request also internships in non-university research institutions or in industry are possible, if supervised by a faculty member. • The duration of a project can be chosen freely. The contact time is approximat
Necessary and useful knowledge	• general knowledge about the research field discussed. • to be announced by practical supervisor
Specialities	The student can pursue up to three independent research projects with a minimum of 4 CP each and a maximum of 12 CP for all projects together.
Usability	
Form of testing and examination	defined by lecturer before beginning of practical, no grades will be given
Term	Winter semester/Summer semester
Duration	1 semester

3.1 Astronomy and Astrophysics

Table 3.1.1: Specialization Astronomy and Astrophysics

Module code	Module	LP/CP	Term
MVAstro0	Introduction to Astronomy and Astrophysics	8	WiSe
MVAstro1	Astronomical Techniques (compact)	6	WiSe
MVAstro2	Stellar Astronomy and Astrophysics	6	SuSe
MVAstro3	Galactic and Extragalactic Astronomy	6	SuSe
MVAstro4	Cosmology (compact)	4	SuSe

Table 3.1.2: Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Laboratory Course Astrophysics I	2	WiSe/SuSe
MVSpec	Laboratory Course Astrophysics II	2	WiSe/SuSe
MVSpec	Observing the Big Bang	3	WiSe
MVSem	Advanced Seminar on Astronomy or Astrophysics	6	WiSe/SuSe
MVRS	Research Seminar on Special Topics of Astronomy or Astrophysics	2	WiSe/SuSe
MVJC	Journal Club on Astronomy or Astrophysics	2	WiSe/SuSe

Table 3.1.3 MSc Model study plan “Astronomy/Astrophysics”

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical Astrophysics (8 CP MKTP2)	Astronomical Techniques (8 CP MKEP5)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization	Advanced Seminar (6 CP MVSem)			
	MVMod: 14 CP + 6 P = 20 CP			
	Cosmology (8 CP MKTP5)	Stellar Astronomy and Astrophysics (6CP MVAstro2)		
		Oral examination 6 CP		
Options		Galactic and Extragalactic Astronomy (6CP MVAstro3)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.1.4 MSc Model study plan “Astronomy/Astrophysics”

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Astronomical Techniques (8 CP MKEP5)	Theoretical Astrophysics (8 CP MKTP2)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 14 CP + 6 P = 20 CP			
	Stellar Astronomy and Astrophysics (6CP MVAstro2)	Cosmology (8 CP MKTP5)		
		Oral examination 6 CP		
Options	Galactic and Extragalactic Astronomy (6CPMVAstro3)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.1.5 MSc Model study plan “Cosmology”

[Beginning: winter semester]

<table>
<tr><th>Study block</th><th>1st Semester</th><th>2nd Semester</th><th>3rd Semester</th><th>4th Semester</th></tr>
<tr><td>Core courses & research modules</td><td>Cosmology
(8 CP MKTP5)</td><td>General Relativity
(8CP MKTP3)</td><td>Scientific Specialization
(15 CP MFS)
Methods and Project Planning
(15 CP MFP)</td><td>Master Thesis
(30 CP MFA)</td></tr>
<tr><td rowspan="4">Specialization</td><td>Advanced Seminar
(6 CP MVSem)</td><td></td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td colspan="2">MVMod: 14 CP + 6 P = 20 CP</td></tr>
<tr><td rowspan="2">Theoretical Astrophysics
(8 CP MKTP2)</td><td>Galactic and Extragalactic Astronomy
(6 CP MVAstro3)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Quantum Field Theory
(8 CP MKTP4)</td><td>Stellar Astronomy and Astrophysics
(6 CP MVAstro2)</td></tr>
<tr><td colspan="2">Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences</td></tr>
<tr><td>Total CPs</td><td colspan="2">min. 60 CP</td><td>30 CP</td><td>30 CP</td></tr>
</table>

Table 3.1.6 MSc Model study plan “Cosmology”

[Beginning: summer semester]

<table>
<tr><th>Study block</th><th>1st Semester</th><th>2nd Semester</th><th>3rd Semester</th><th>4th Semester</th></tr>
<tr><td>Core courses & research modules</td><td>General Relativity
(8CP MKTP3)</td><td>Cosmology
(8 CP MKTP5)</td><td>Scientific Specialization
(15 CP MFS)
Methods and Project Planning
(15 CP MFP)</td><td>Master Thesis
(30 CP MFA)</td></tr>
<tr><td rowspan="4">Specialization</td><td></td><td>Advanced Seminar
(6 CP MVSem)</td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td colspan="2">MVMod: 14 CP + 6 P = 20 CP</td></tr>
<tr><td rowspan="2">Galactic and Extragalactic Astronomy
(6 CP MVAstro3)</td><td>Theoretical Astrophysics
(8 CP MKTP2)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Stellar Astronomy and Astrophysics
(6 CP MVAstro2)</td><td>Quantum Field Theory
(8 CP MKTP4)</td></tr>
<tr><td colspan="2">Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences</td></tr>
<tr><td>Total CPs</td><td colspan="2">min. 60 CP</td><td>30 CP</td><td>30 CP</td></tr>
</table>

Code: MVAstro0	Course title: Introduction to Astronomy and Astrophysics
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	Lecture Introduction to "Astronomy and Astrophysics" • Astronomical basics: astronomical observations, methods and instruments; orientation at the celestial sphere; fundamental terms of electromagnetic radiation; distance determination, Earth-Moon system; terrestrial and gas planets, small bodies; extra-solar-planets • Inner structure of stars: state variables, stellar atmospheres and line spectra; Hertzsprung-Russell diagram; fundamental equations, energy transfer and opacity; nuclear reaction rates and tunnelling; nuclear fusion reactions • Stellar evolution: Main sequence, giants and late phases; white dwarfs, Chandrasekhar limit; supernovae, neutron stars, Pulsars and supernova remnants; binaries and multiple systems; star clusters • Interstellar medium: cold, warm, hot gas phases dust, cosmic rays, magnetic fields; ionization and recombination, Stroemgren spheres; heating and cooling; star formation, matter cycle, chemical enrichment • Galaxies: Structure and properties of normal galaxies and the Milky Way; scaling relations; integrated spectra, luminosity function; cosmological evolution of star formation; Black Holes in galaxies, active galaxies and their properties, unified models • Galaxy clusters: optical properties and cluster gas; hydrostatic model; scaling relations; number densities and evolution • Gravitational lensing: Concepts, mass distribution in galaxies and galaxy clusters; cosmological lensing effect • Large scale distribution of galaxies and gas: Structure in the spatial galaxy distribution; redshift effects; biasing; Lyman-α-forest; Gunn-Peterson effect and cosmic reionization • Cosmology: Friedmann-Lemaître models, cosmological standard model; origin and evolution of structures; halos of Dark Matter; Formation of galaxies
Objectives	The students have gained basic knowledge and understanding of astronomical objects, measuring units and methods, and the relevant astrophysical processes. They have a firm grasp of the fundamental interrelations of objects and processes on different scales. They are able to reproduce the basic features of the modern world view including the physical reasoning, and connect astronomical and astrophysical phenomena to previously acquired knowledge in physics.
Module parts and teachings methods	• Lecture on Introduction to Astronomy and Astrophysics with Exercises (6 hours/day: 3 weeks block course in Sept./Oct.)

Necessary and useful knowledge	Necessary useful knowledge is basic knowledge in physics and mathematics, especially mechanics, electromagnetic radiation, thermodynamics Recommended literature will be announced by lecturer
Specialities	block course, exercises with homework, equivalent to BSc-Module parts WPAstro 1+2.
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester
Duration	1 semester

Code: MVAstro1	Astronomical Techniques (Compact)
Type	Lecture and laboratory course
Language	English
Credit points	6
Workload	180 h
Contents	Module Part 1: Lecture "Astronomical Techniques (Compact)" (4 CP) • Signals, optics, atmosphere (3): types of measurable signals, flux, geometrical optics, optical elements, Rayleigh criterion, atmospheric effects, seeing, refraction, airmass, speckles and lucky imaging, optical aberrations and their correction. • Telescope design, mounts, observatory engineering (1): types of mounts, telescope foci, applications, space telescopes, mirror designs, local climate control, site selection criteria. • Adaptive optics (1): Basics; isoplanatism, guide stars, wave front sensors; applications. • Detectors (2): solid-state crystals, types of semiconductors, photoconductors, MOS capacitors, photomultipliers, photometers, detector characterization, CCDs. • CCD data processing, photometry, spectroscopy (4): Response function, preprocessing, combining images, digital photometry, time series, surveys, extinction, transformation to a standard system. Dispersing elements; slitless, slit, fiber, & IFU spectroscopy, applications. • Other wavelength regions (2): IR, radio, X-ray, and gamma ray detectors and applications. • Astroparticle telescopes, gravitational waves, in-situ exploration (2): Cherenkov and neutrino detectors; gravitational waves; remote sensing, in-situ exploration, examples. Module Part 2: Astrophysical Laboratory Course II (2 CP) By means of well-posed astrophysical problems on the following topics advanced astronomical/astrophysical techniques concerning sampling, data bases and statistical methods will be trained: • Spectroscopic observations: observation, data reduction, astrophysical interpretation • optical design: construct a telescope, image errors, corrections for Hubble space telescope; • extrasolar planets: Discovering methods, properties and limitations, high precision photomety; • Galaxy evolution: Morphological types, statistical properties, biases, quasar properties; • Observational cosmology: standard candles, Cosmic microwave background, determination of cosmological parameters

Objectives	Upon completion of this course, the students have achieved firm insight into concepts, technologies, and the underlying physical principles and limitations of modern observational techniques along with scientific applications. They have knowledge of basic detector designs for different types of radiation and particles. They have gained practical experience in taking, reducing, and interpreting observational data. They understand the environmental influence on astronomical observations.
Module parts and teachings methods	• Lecture on Observational Methods (2 hours/week) • Exercises (1 hour / week) • Laboratory Course (1 week block course)
Necessary and useful knowledge	• Knowledge of the introductory astronomy lectures "Introduction to Astronomy and Astrophysics I and II" (WPAstro or MVAstro0). • Recommended literature: - Chromey: To Measure the Sky (CUP). - Kitchin: Astrophysical Techniques (CRC Press).
Specialities	Exercises; laboratory course (a 1 week block course). Credit points can only be obtained for either MVAstro1 or for MKEP5, but not for both due to topical overlap.
Usability	
Form of testing and examination	written exam at the end of the course.
Term	Winter semester
Duration	1 semester

Code: MVAstro2	Course title: Stellar Astronomy and Astrophysics
Type	Lecture with exercises, seminar
Language	English
Credit points	6
Workload	180 h
Contents	- Module Part 1: Lecture "Stellar Astronomy and Astrophysics" (4 CP) • Structure and evolution of stars (5): Stellar structure equations, energy transfer, stellar models; evolution of stars with different masses; stellar pulsations; degenerated equation of state; evolution of binary systems; final stages and supernovae • Nuclear processes and element formation (3): Fusion processes, cross sections and tunneling; neutrinos as tracers of nuclear fusion processes; production of higher order elements, resonances; r- and s-process • Stellar atmospheres (5): radiative transfer, grey atmosphere, local thermodynamic equilibrium. Theory of line spectra; determination of stellar parameters using spectral analysis; stellar winds • Formation of stars and planets (2): Conditions for star formation, metals, dust and molecular clouds; early phases of star formation, proto-stellar discs; planet formation, extrasolar planets; enrichment with heavy elements - Module Part 2: Seminar (2 CP) • Presentations and discussions on actual topics in stellar astronomy and astrophysics
Objectives	After completing this course, the students have a firm grasp of the physical processes determining the inner structure of stars, the observational properties including radiative transfer in the atmosphere, and the evolutionary states. They have a basic understanding of the star formation process in the interstellar medium, and they are able to reproduce the observational properties of stars in the Hertzsprung-Russell-Diagram.
Module parts and teachings methods	• Lecture on Stellar Astronomy and Astrophysics (2 hours/week) • Exercise (1 hour/week) • Seminar on Special Topic in Stellar Astronomy and Astrophysics (2 hours/week)
Necessary and useful knowledge	• content of WPAstro/MVAstro0, MKTP2 • to be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Summer semester, sometimes the lecture part of this module is offered as block course

Duration	1 semester

Code: MVAstro3	**Galactic and Extragalactic Astronomy**
Type	Lecture with exercises, seminar
Language	English
Credit points	6
Workload	180 h
Contents	Module Part 1: Lecture “Galactic and Extragalactic Astronomy” (4 CP) • Galaxy types and classification, correlations with physical properties, stellar populations, population synthesis, chemical evolution concepts and models (2); • Milky Way (3): halo, bulge / pseudo bulge, central black hole, thin and thick disk, spiral structure, star clusters, star formation history and chemical enrichment, formation scenarios (e.g., Eggen-Lynden-Bell-Sandage), multi-phase interstellar medium, dust, Galactic fountain, satellites, substructure problem, Local Group; • Spiral and elliptical galaxies (4): Surface photometry, profiles, origin of spiral structure, mass measurement methods, rotation / velocity dispersion, Tully-Fisher / Faber-Jackson relation, fundamental plane, super massive black holes, active galaxies; • Groups and clusters (3): morphology-density relation etc., mass measurements, gravitational lensing, luminosity functions, interactions; intergalactic gas; dark matter; • Growth of structure (3): Origin of matter and elements, large-scale-structure formation, large-scale matter distribution, redshift surveys, weak lensing, galaxy formation and evolution, red / blue sequence, downsizing, scaling relations, Butcher-Oemler effect, cosmic star formation history, Lyman alpha forest, high-redshift universe, reionization, problems in galaxy formation. Module Part 2: Seminar (2 CP) • Presentations and discussions on selected topics in Galactic and extragalactic astronomy
Objectives	When successfully completing this course, the students are able to report on the properties of the wide range of galaxy types, understand their origin and evolution, and can elucidate the physical factors governing their evolution. They understand the main physical processes that shape the appearance of galaxies and galaxy clusters. They know about the connection between cosmological structure formation and the populations of visible objects. They have gained experience in applying dimensional and scaling arguments to estimate the relative importance of different physical processes.
Module parts and teachings methods	• Lecture on “Galactic and Extragalactic Astronomy” (2 hours/week) • Exercise (1 hour/week) • Seminar on selected topics in “Galactic and Extragalactic Astronomy” (2 hours/week)

Necessary and useful knowledge	• Necessary knowledge: content of WPAstro/MVAstro0, MKTP2 • Recommended literature: Sparke & Gallagher: "Galaxies in the Universe" (CUP)
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Summer semester, sometimes lecture part is offered as block course
Duration	1 semester

Code: MVAstro4	**Cosmology (compact)**
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• Friedmann-Lemaître-cosmologies: cosmological redshift, parameter set, effects of curvature and of the cosmological constant, Hubble expansion and Cepheid-measurements • Age of the Universe: age from the cosmological model, radiometric dating and nuclear cosmochronology, age of the oldest cosmic objects • Distance-redshift relation of standard candles: distance-redshift relations, calibration of supernovae, acceleration and dimming, determination of densities and equations of state, evidence for dark energy • Abundance of chemical elements: thermal evolution, big bang nucleosynthesis, other modes of nucleosynthesis (stellar, spallation, explosive), reaction chains, element abundances • Cosmic microwave background: formation of atoms, simplified description of temperature anisotropies, measurement results and conclusions from them (in particular spatial flatness), secondary anisotropies • Cosmic structures: linear growth, need for (nonbaryonic) dark matter, large-scale distribution of galaxies, cosmic web • Formation of galaxies: gravitational collapse, flat rotation curves and virial equilibria, need for dark matter, abundance of haloes • Gravitational lensing: gravitational light deflection, lens equation, weak and strong lensing, measurements of lensing effects and their inversion
Objectives	In this course, students gain fundamental understanding of the cosmological standard model and the cosmological evolution, including the impact of the basic observations and the connection to the physical framework. They gain a solid overview of the empirical basis of modern cosmology.
Module parts and teachings methods	• Lecture on Cosmology (2 hours/week) • Exercise with homework (1 hours/week)
Necessary and useful knowledge	• Necessary knowledge: content of WPAstro/MVAstro0, PTP-1, -2 and -3 • Literature: to be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course

Term	Summer semester, sometimes offered as block course
Duration	1 semester

3.2 Atomic, Molecular and Optical Physics

Table 3.2.1: Specialization Atomic, Molecular and Optical Physics

Module code	Module	LP/CP	Term
MVAMO1	Experimental Optics and Photonics	4	WiSe
MVAMO2	Advanced Quantum Theory	4	SuSe
MVAMO3	Experimental Methods in Atomic & Molecular Physics	4	SuSe

Table 3.2.2: Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Quantum Gases	3	WiSe/SuSe
MVSpec	Quantum Information	3	WiSe/SuSe
MVSpec	Special Topics in Atomic and Molecular Physics	3	WiSe/SuSe
MVSpec	Quantum Dynamics and Control	3	WiSe/SuSe
MVSpec	Quantum Electrodynamics	3	WiSe/SuSe
MVSpec	Precision Experiments in AMO Physics	3	WiSe/SuSe
MVSpec	Atomic and Molecular Spectroscopy	3	WiSe/SuSe
MVSpec	Atom Light Interactions	3	WiSe/SuSe
MVSpec	Theoretical Quantum Optics	3	WiSe/SuSe
MVSpec	Laser Physics	3	WiSe/SuSe
MVSpec	Atoms and Molecules in Strong Fields	3	WiSe/SuSe
MVSem	Advanced Seminar on Modern Topics in Atomic, Molecular and Optical Physics	6	WiSe/SuSe

Table 3.2.3 MSc Model study plan “Atomic, Molecular and Optical Physics”

[Beginning: winter semester]

<table>
<tr><th>Study block</th><th>1st Semester</th><th>2nd Semester</th><th>3rd Semester</th><th>4th Semester</th></tr>
<tr><td>Core courses
& research modules</td><td>Advanced Atomic, Molecular and Optical Physics
(8 CP MKEP3)
Theoretical Statistical Physics
(8 CP MKTP1)</td><td></td><td>Scientific Specialization
(15 CP MFS)
Methods and Project Planning
(15 CP MFP)</td><td>Master Thesis
(30 CP MFA)</td></tr>
<tr><td rowspan="4">Specialization</td><td></td><td>Advanced Seminar
(6 CP MVSem)</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td colspan="2">MVMod: 12 CP + 6 P = 18 CP</td></tr>
<tr><td rowspan="2">Experimental Optics and Photonics
(4CP MVAMO1)</td><td>Advanced Quantum Theory
(4 CP MVAMO2)
Experimental Methods in Atomic, Molecular and optical Physics
(4 CP MVAMO3)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td></td><td>Condensed Matter Physics
(8 CP MKEP2)</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences</td></tr>
<tr><td>Total CPs</td><td colspan="2">min. 60 CP</td><td>30 CP</td><td>30 CP</td></tr>
</table>

Table 3.2.4 MSc Model study plan “Atomic, Molecular and Optical Physics”

[Beginning: summer semester]

<table>
<tr><th>Study block</th><th>1st Semester</th><th>2nd Semester</th><th>3rd Semester</th><th>4th Semester</th></tr>
<tr><td>Core courses
& research modules</td><td></td><td>Advanced Atomic, Molecular and Optical Physics
(8 CP MKEP3)
Theoretical Statistical Physics
(8 CP MKTP1)</td><td>Scientific Specialization
(15 CP MFS)
Methods and Project Planning
(15 CP MFP)</td><td>Master Thesis
(30 CP MFA)</td></tr>
<tr><td rowspan="4">Specialization</td><td>Advanced Seminar
(6 CP MVSem)</td><td></td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td colspan="2">MVMod: 12 CP + 6 P = 18 CP</td></tr>
<tr><td rowspan="2">Advanced Quantum Theory
(4 CP MVAMO2)
Experimental Methods in Atomic, Molecular and optical Physics
(4 CP MVAMO3)</td><td>Experimental Optics and Photonics
(4CP MVAMO1)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Condensed Matter Physics
(8 CP MKEP2)</td><td></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences</td></tr>
<tr><td>Total CPs</td><td colspan="2">min. 60 CP</td><td>30 CP</td><td>30 CP</td></tr>
</table>

Code: MVAMO1	Course title: Experimental Optics and Photonics
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• Ray optics • Wave optics • Beam optics, Gaussian optics • Fourier optics • Interference and coherence • Photons and atoms • Laser theory and lasertypes • Ultra-short laser pulses • Non-linear optics • Modern applications
Objectives	After completing this course the students will be able to • describe the basic principles and experimental methods of optics and photonics, • analyse standard experimental approaches to optics and photonics, • design experimental set-ups in optics and photonics, • apply the methods to simple experimental examples.
Module parts and teachings methods	• Lecture (2 hours/week) • Exercise with homework (1 hours/week)
Necessary and useful knowledge	PEP1-PEP4, PTP1-PTP4
Specialities	exercises with homework
Usability	
Form of testing and examination	To be defined by lecturer before beginning of course.
Term	Winter semester
Duration	1 semester

Code: MVAMO2	**Course title: Advanced Quantum Theory**
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	Selection out of the topics: • Quantum theory of matter (Schrödinger equation, bosons and fermions, spin and statistics) • Time-dependent quantum phenomena (scattering, atoms and molecules in external fields) • Theory of quantum states (system and environment, pure and mixed states, density operator, entanglement, quantum information) • Quantum theory of light and matter (quantized fields, interaction with atoms, quantum optics) • Open quantum systems (matter and radiation, decoherence, non-equilibrium phenomena) • Relativistic quantum theory (Dirac equation, relativistic light-matter interaction)
Objectives	After completing this course the students will be able to • describe the fundamental concepts of quantum physics and the relevant theoretical methods, • analyse standard experimental approaches using the relevant theoretical methods, • solve problems in quantum physics and quantum optics, • apply the relevant theoretical methods to model concrete physical situations.
Module parts and teachings methods	• Lecture (2 hours/week) • Exercise (1 hours/week)
Necessary and useful knowledge	PEP1-PEP4, PTP1-PTP4
Specialities	-
Usability	
Form of testing and examination	To be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

Code: MVAMO3	**Course title: Experimental Methods in Atomic, Molecular and Optical Physics**
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	Selection out of the following topics: • Atom-light interactions • Spectroscopy and metrology • Matter waves • Cooling and trapping • Mass measurements • Single atoms and molecules • Cavity Quantum Electrodynamics • Quantum information • Quantum gases • Collisions • Fento- and attosecond processes
Objectives	After completing this course the students will be able to • describe modern aspects of experimental research in atomic, molecular and optical physics, • analyse standard experimental approaches of atomic, molecular and optical physics, • design simple experimental set-ups in atomic, molecular and optical physics, • apply the methods to simple practical examples.
Module parts and teachings methods	• Lecture (2 hours/week) • Exercise (1 hours/week)
Necessary and useful knowledge	PEP1-PEP4, PTP1-PTP4
Specialities	-
Usability	
Form of testing and examination	To be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

3.3 Biophysics

Table 3.3.1: Specialization Biophysics

Module code	Module	LP/CP	Term
MVBP1	Experimental Biophysics	6	WiSe
MVBP2	Theoretical Biophysics	6	SuSe

Table 3.3.2: Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Optics in Biophysics	4	WiSe/SuSe
MVSpec	Bio-photonics	2	WiSe/SuSe
MVSpec	Astrobiophysics III	2	WiSe/SuSe
MVSpec	Scientific Visualization	2	WiSe/SuSe
MVSpec	Nonlinear Dynamics	2	WiSe/SuSe
MVSpec	Stochastic Dynamics	2	WiSe/SuSe
MVSpec	Radiation Biophysics	2	WiSe/SuSe
MVSem	Advanced Seminar on Biophysics	6	WiSe/SuSe
MVRS	Research Seminar on special topics of Biophysics	2	WiSe/SuSe
MVJC	Journal Club on Biophysics	2	WiSe/SuSe

Table 3.3.3 MSc Model study plan “Biophysics”

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical Statistical Physics (8 CP MKTP1)	Condensed Matter Physics (8 CP MKEP2)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 16 CP + 6 P = 22 CP			
	Experimental Biophysics (6CP MVBP1) Advanced Lecture on Special Topics (2 CP MVSpec)	Theoretical Biophysics (6CP MVBP2) Advanced Lecture on Special Topics (2 CP MVSpec)		
		Oral examination 6 CP		
Options	Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3) Physics of imaging1 (4CP MWInf5)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.3.4 MSc Model study plan “Biophysics”

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed Matter Physics (8 CP MKEP2)	Theoretical Statistical Physics (8 CP MKTP1)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization	Advanced Seminar (6 CP MVSem)			
	MVMod: 16 CP + 6 P = 22 CP			
	Theoretical Biophysics (6CP MVBP2) Advanced Lecture on Special Topics (2 CP MVSpec)	Experimental Biophysics (6CP MVBP1) Advanced Lecture on Special Topics (2 CP MVSpec)		
		Oral examination 6 CP		
Options		Image Processing (7 CP MWInf6)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP	30 CP	30 CP	

Code: MVBP1	**Course title: Experimental Biophysics**
Type	Lecture with exercises
Language	English
Credit points	6
Workload	180 h
Contents	• Methods of structural biology (X-Rays, EM, NMR, LM) • Membranes and biological energy • Measurement of neural activity • Single Molecule Spectroscopy • Imaging of living tissue • Information in living tissue • Chemo-mechanical coupling • Catalysis
Objectives	After successful finishing of the module • the students will have advanced knowledge of concepts of experimental biophysics, • the students can assess and use current biophysical literature.
Module parts and teachings methods	• Lecture on "Introduction to Biophysics" (4 hours/week) • Exercise (2 hours/week)
Necessary and useful knowledge	• content of PEP4, UKBio1, UKBio2 • to be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester
Duration	1 semester

Code: MVBP2	**Course title: Theoretical Biophysics**
Type	Lecture with exercises
Language	English
Credit points	6
Workload	180 h
Contents	• Macromolecules - General properties of macromolecules: Freely jointed chain, the Gaussian chain model, elastic rod model, self avoiding chains, conformations and energy landscapes, macromolecules in solution, macromolecules at a surface - Intermolecular interactions and electrostatic screening - Helix-Coil transition - DNA melting -Polyelectrolytes: The Poisson-Boltzmann equation - Proteins: Protein folding numerical approaches, folding as a spin glass problem, protein-protein interactions - Chromatin: Chromatin models, force-extension behaviour of folded macromolecules - Genes: Gene expression and genetic code • Membranes - Self–assembly of micelles - Surface behaviour of lipids: differential geometry of surfaces, membrane elasticity and bending energy, membrane fluctuations - Structure of Lipids -Cell Membranes • Transport - Diffusion - Polymer dynamics: Rouse Model, hydrodynamic interactions • Networks - Gels - Metabolic Networks: Boolean networks, scale-free networks, robustness of networks • Molecular Motors - Polymerization of cell filaments - Brownian ratchet - A basic model of a molecular motor • Statistical Analysis - Bayesian Analysis - Monte Carlo Methods - Hidden Markov Models
Objectives	After successful finishing of the module • the students will have advanced knowledge of theoretical biophysics,

	• the students will have practical experience with theoretical calculations of bio-systems.
Module parts and teachings methods	• Lecture on “Theoretical Biophysics” (4 hours/week) • Exercise (2 hour/week)
Necessary and useful knowledge	• basics of classical mechanics, electrodynamics and statistical mechanics • to be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

3.4 Computational Physics

Table 3.4.1: Specialization Computational Physics

Module code	Module	LP/CP	Term
MVComp1	Fundamentals of Simulation Methods	8	WiSe
MVComp2	Computational Statistics and Data Analysis	6	SuSe

Table 3.4.2: Specialization Computational Physics; Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Advanced Monte Carlo Methods	3	WiSe/SuSe
MVSpec	Advanced Parallel Computing	4-6	WiSe/SuSe
MVSpec	Computational Fluid Dynamics	4-6	WiSe/SuSe
MVSpec	Computational Imaging	4-6	WiSe/SuSe
MVSpec	Computational Optics	4-6	WiSe/SuSe
MVSpec	GPU programming	4	WiSe/SuSe
MVSpec	Image Analysis	8	WiSe/SuSe
MVSpec	Introduction to High-Performance Computing	4-6	WiSe/SuSe
MVSpec	Inverse Problems	8	WiSe/SuSe
MVSpec	Machine Learning	8	WiSe/SuSe
MVSpec	Radiative Transfer	4	WiSe/SuSe
MVSpec	Scientific Programming	4-6	WiSe/SuSe
MVSpec	Volume Visualization	8	WiSe/SuSe
MVSem	Computer Vision	6	WiSe/SuSe

Table 3.4.3 MSc Model study plan "Computational Physics"

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical Statistical Physics (8 CP MKTP1)	One core course MKEP* or MKTP*	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 16CP + 6 P = 22 CP			
	Fundamentals of Simulation Methods (8 CP MVComp1) or MVSpec specialized lecture	Computational Statistics and Data Analysis (6 CP MVComp2) or MVSpec specialized lecture		
		Oral examination 6 CP		
Options	Advanced Lecture on Special Topics (4CP MVSpec)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.4.4 MSc Model study plan "Computational Physics"

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	One core course MKEP* or MKTP*	Theoretical Statistical Physics (8 CP MKTP1)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 16CP + 6 P = 22 CP			
	Computational Statistics and Data Analysis (6 CP MVComp2) or MVSpec specialized lecture	Fundamentals of Simulation Methods (8 CP MVComp1) or MVSpec specialized lecture		
		Oral examination 6 CP		
Options	Advanced Lecture on Special Topics (4CP MVSpec)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVComp1	**Course title: Fundamental of Simulation Methods**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Basic concepts of numerical simulations, continuous and discrete simulations • Discretization of ordinary differential equations, integration schemes of different order • N-body problems, molecular dynamics, collisionless systems • Discretization of partial differential equations • Finite element and finite volume methods • Lattice methods • Adaptive mesh refinement and multi-grid methods • Matrix solvers and FFT methods • Monte Carlo methods, Markov chains, applications in statistical physics
Objectives	After completion of this module, the students are endowed with the capacity to identify and classify numerical problems. They have reached active understanding of applicable numerical methods and algorithms. They are able to solve basic physical problems with adequate numerical techniques and to recognize the range of validity of numerical solutions.
Module parts and teachings methods	• Lecture on “Fundamentals of Simulation Methods” (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• not required but useful is prior knowledge in a programming language and experience with plotting software • will be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester
Duration	1 semester

Code: MVComp2	**Course title: Computational Statistics and Data Analysis**
Type	Lecture with exercises
Language	English
Credit points	6
Workload	180 h
Contents	• Axioms of Probability Theory; random variables, important distributions • Bayesian inference • Linear regression, nonlinear regression • Regularized regression to fit high-dimensional data • Hypothesis testing: fundamental concepts • Parametric and nonparametric tests • Classification • Cluster analysis • Model selection
Objectives	After completion of this module, the students understand fundamental concepts of stochastics, and are able to relate them to concrete problems. They understand and are alert of possible pitfalls such as overfitting, multiple comparisons, or susceptibility to outliers. They know and are able to apply basic countermeasures and they have access to more advanced literature on the subject. Students are familiar with relevant high-level languages and statistical programming libraries, and know how to apply them to real-world data provided in the exercises.
Module parts and teachings methods	• Lecture on Computational Statistics and Data Analysis (2 hours/week) • Exercise (2 hour/week) with computational homework
Necessary and useful knowledge	• Linear Algebra • to be announced by lecturer
Specialities	exercises with computational homework
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

3.5 Condensed Matter Physics

Table 3.5.1: Specialization Condensed Matter Physics

Module code	Module	LP/CP	Term
MVCMP1	Low Temperature Physics	8	WiSe/SuSe
MVCMP2	Surfaces and Nanostructures	6	WiSe
MVCMP3	Electronic Correlations and Magnetism	8	SuSe/WiSe

Table 3.5.2: Specialised lectures and seminars

(experimental condensed matter physics, organic electronics):

[The lectures and seminars listed here will be offered only on an irregular basis. This list may not be complete; additional lectures will be offered by guests and junior lecturers. Teaching hours and CP may vary, too.]

Code	Module	LP/CP	Term
MVSpec	Low Temperature Detectors	4	WiSe/SuSe
MVSpec	Nanoscale Physics	4	WiSe/SuSe
MVSpec	Optical Properties of Condensed Matter	3	SuSe
MVSpec	Quantum Magnetism	4	WiSe/SuSe
MVSpec	Quantum Fluids	4	WiSe/SuSe
MVSpec	Superconductors	4	WiSe/SuSe
MVSpec	Semiconductor Physics I and II	2/2	WiSe/SuSe
MVSpec	Organic electronics	4	WiSe
MVSpec	Organic semiconductors and molecular solids	4	SuSe
MVSem	Advanced Seminar on Condensed Matter Physics	6	SuSe
MVRS	Research Seminar on special topics of Condensed Matter Physics	2	WiSe/SuSe
MVJC	Journal Club on Condensed Matter Physics (including organic condensed matter)	2	WiSe/SuSe

Table 3.5.3 MSc Model study plan "Experimental Condensed Matter Physics"

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical statistical physics (8 CP MKTP1)	Condensed matter physics (8 CP MKEP2)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization	Advanced Seminar (6 CP MVSem)			
	MVMod: 14 CP + 6 P = 20 CP			
	Specialized lectures in Condensed Matter Physics (6 CP MVSpec) or Low Temperature Physics (8 CP MVCMP1) or Surfaces and Nanostructures (6 CP MVCMP2)	Experimental Methods in Atomic and Molecular Physics (4 CP MVAMO3) or Electron Correlations & Magnetism (8 CP MVCMP3)		
		Oral examination 6 CP		
Options	Molecular and Optical Physics (8 CP MKEP3) or Condensed Matter Theory (8CP MVTheo2)	Journal Club or specialized Lecture on Condensed Matter Physics (2 CP MVJC or MVSpec)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.5.4 MSc Model study plan "Experimental Condensed Matter Physics"

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed Matter Physics (8 CP MKEP2)	Theoretical Statistical Physics (8 CP MKTP1)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization	Advanced Seminar (6 CP MVSem)			
	MVMod: 14 CP + 6 P = 20 CP			
	Electron Correlations & Magnetism (8 CP MVCMP3) Specialized lectures on Condensed Matter Physics (4 CP MVSpec)	Low Temperature Physics (8CP MVCMP1) or Surfaces & Nanostructures (6CP MVCMP2)		
		Oral examination 6 CP		
Options	Journal Club or specialized Lecture on Condensed Matter Physics (2 CP MVJC or MVSpec)	Molecular and Optical Physics (8 CP MKEP3) or Condensed Matter Theory (8CP MVTheo2)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVCMP1	**Course title: Low Temperature Physics**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Properties of quantum fluids: superfluid 3He and 4He, normal-fluid 3He, • Properties of solids at low temperatures: specific heat, thermal transport, electrical conductivity, magnetic properties, atomic tunnelling systems, superconductivity • cooling techniques, thermometry
Objectives	After completing this module • students have insight into fundamentals of quantum fluids and solids, • they understand the theoretical and experimental basics of condensed matter physics at low temperatures, • they have detailed knowledge about modern experimental techniques to obtain and measure low temperatures.
Module parts and teachings methods	• Lecture on “Low Temperature Physics” (4 hours/week) • Exercise (2 hour/week) and home works
Necessary and useful knowledge	• content of PEP5 (necessary); PTP4, MKEP2 (useful) • to be announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester/Summer semester
Duration	1 semester

Code: MVCMP2	Course title: Surfaces and Nanostructures
Type	Lecture with exercises; visits to laboratory
Language	English
Credit points	6
Workload	180 h
Contents	• Structure, electronic and vibrational properties of surfaces • Adsorbates, thin films, and nano-objects on surfaces • Optical properties of surfaces, thin films, and nanoparticles • Electronic dimension and quantum effects
Objectives	Students understand the theoretical and experimental basics of the physics of surfaces and nanostructures including important preparation issues. They became acquainted with the current research and related applications.
Module parts and teachings methods	• Lecture on "Surfaces and Nanostructures" (4 hours/week) • Exercises with homework (1 hour/week) • 2 Visits to Laboratory
Necessary and useful knowledge	• content of PEP4, PEP5, PTP4 • to be announced by lecturer
Specialities	the lecture course includes 2 visits to the laboratory and weekly homework.
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester
Duration	1 semester

Code: MVCMP3	Course title: Electronic Correlations and Magnetism
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Magnetism and electronic properties of atoms and ions • Electronic properties of solids, crystal field theory • Magnetism in metals, micro- and nanomagnetism • Hubbard model, Mott insulators • Magnetism in insulators, magnetic interactions • Collective phenomena: spin ordering and phase transitions • Magnetoresistive Effects • Quantum Magnets • Magnetism and high-temperature superconductivity
Objectives	Students have gained insight into fundamentals of magnetism and electron correlations in solids. They have learned about the principles of advanced experimental methods and their interpretation, and they understand the basic concepts of electron correlation in solids and its implications. They can apply this knowledge to understand and to assess modern research trends in condensed matter physics.
Module parts and teachings methods	• Lecture on “Electronic Correlations and Magnetism” (4 hours/week) • Exercises with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP5 (necessary); PTP4, MKEP2 (useful) • will be announced on the course web page.
Specialities	exercises with homework.
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Winter semester/Summer semester
Duration	1 semester

3.6 Environmental Physics

Table 3.6.1: Specialization Environmental Physics

Module code	Module	LP/CP	Term
MVEnv1	Atmospheric Physics	4	WiSe
MVEnv2	Physics of Terrestrial Systems	4	WiSe
MVEnv3	Physics of Aquatic Systems	4	SuSe
MVEnv4	Physics of Climate	4	SuSe
MVEnv5	Practical Environmental Physics	1-7	SuSe

Table 3.6.2: Specialization Environmental Physics

Specialised lectures and seminars [The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Special Topics Environmental Physics	2	WiSe/SuSe
MVSem	Advanced Seminar on Environmental Physics	6	WiSe/SuSe
MVRS	Research Seminar on special topics of Environmental Physics	2	WiSe/SuSe
MVJC	Journal Club on Environmental Physics	2	WiSe/SuSe

Table 3.6.3 MSc Model study plan “Environmental Physics“

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical Statistical Physics (8 CP MKTP1) Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3)		Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 14 CP + 8 P = 22 CP			
	Environmental Physics (8 CP MKEP4)	Physics of Aquatic Systems (4 CP MVEnv3) Physics of Climate (4 CP MVEnv4)		
		Oral examination 6 CP		
Options	Specialized lectures on Environmental Physics (3 CP MVSpec)	Practical Environmental Physics (7 CP MVEnv5)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.6.4 MSc Model study plan “Environmental Physics “

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed matter physics (8 CP MKEP2)	Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 14 CP + 8 P = 22 CP			
	Environmental Physics (8 CP MKEP4)	Atmospheric Physics (4 CP MVEnv1) Physics of Terrestrial Systems (4 CP MVEnv2)		
		Oral examination 6 CP		
Options	Physics of Climate (4 CP MVEnv4) Practical Environmental Physics (7 CP MVEnv5)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVEnv1	Course title: Atmospheric Physics
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• Physics of the atmosphere (structure, composition, dynamics, global circulation, radiation) • Applications in atmospheric physics (e.g. micro-meteorology, trace gas cycles, atmospheric chemistry, measurement techniques)
Objectives	Students achieve an advanced understanding of the physical and chemical processes in the atmosphere, the methods to study them, and their role in the climate system. They are able to solve advanced problems and interpret the results in the context of current questions in research and application. They can assess and use current scientific literature to further develop their knowledge base, enabling them to conduct independent master research projects in atmospheric physics.
Module parts and teachings methods	• Lecture on "Atmospheric Physics" (2 hours/week) • Exercise with homework (1 hour/week)
Necessary and useful knowledge	• content of MKEP4 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	1-hour written exam
Term	Winter semester
Duration	1 semester

Code: MVEnv2	**Course title: Physics of Terrestrial Systems**
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• Fluids in porous media • Groundwater flow • Soil water flow • Solute transport
Objectives	Students achieve an advanced understanding of the physical processes in terrestrial systems, the methods to study them, and their role in the Earth system. They are able to solve advanced problems and interpret the results in the context of current questions in research and application. They can assess and use current scientific literature to further develop their knowledge base, enabling them to conduct independent master research projects in physics of terrestrial systems.
Module parts and teachings methods	• Lecture on "Soil Physics" (2 hours/week) • Exercise with homework (1 hour/week)
Necessary and useful knowledge	• content of MKEP4 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	1-hour written exam
Term	Winter semester
Duration	1 semester

Code: MVEnv3	Course title: Physics of Aquatic Systems
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• Fundamentals of physical oceanography, limnology, and hydrogeology • Heat and mass transfer between water and atmosphere • Flow and transport in surface and ground water • Tracer methods in the hydrological cycle
Objectives	Students achieve an advanced understanding of the physical processes in aquatic systems, the methods to study them, and their role in the climate system. They are able to solve advanced problems and interpret the results in the context of current questions in research and application. They can assess and use current scientific literature to further develop their knowledge base, enabling them to conduct independent master research projects in physics of aquatic systems.
Module parts and teachings methods	• Lecture on "Physics of Aquatic Systems" (2 hours/week) • Exercise with homework (1 hour/week)
Necessary and useful knowledge	• content of MKEP4 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	1-hour written exam
Term	Summer semester
Duration	1 semester

Code: MVEnv4	**Course title: Physics of Climate**
Type	Lecture with exercises
Language	English
Credit points	4
Workload	120 h
Contents	• The Sun and its variability (orbital and solar physics) • Ocean and atmosphere and their recent changes • Cyrosphere and water cycle • Isotope tools • Radiative transfer and climate • Climate stability and run-away climatevariability • The carbon cycle • Climate sensitivity, heat capacity, response times • Prediction of climate change
Objectives	Students achieve an advanced understanding of the climate system and the methods to study it, including its changes in the past and the modern human impact on it. They are able to solve advanced problems and interpret the results in the context of current research questions and societal implications. They can competently and critically assess the public discourse on climate change on the basis of the current scientific literature. They have developed a knowledge base that enables them to conduct independent master research projects in physics of climate.
Module parts and teachings methods	• Lecture on “Physics of the Climate System” (2 hours/week) • Exercise with homework (1 hour/week)
Necessary and useful knowledge	• content of MKEP4 • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	90 minutes written exam
Term	Summer semester
Duration	1 semester

Code: MVEnv5	**Course title: Practical Environmental Physics**
Type	Practical and laboratory course
Language	English
Credit points	1-7
Workload	30-120 h
Contents	The following topics are offered: • Topic 1: Propagation of electromagnetic waves in soils: TDR and GPR • Topic 2: Measurements of atmospheric photon path lengths by DOAS • Topic 3: Analysis of lake stratification and lake - groundwater interaction • Topic 4: Natural, (low level) radioisotopes as environmental tracers • Topic 5: Imaging of short wind waves • Topic 6: CRD (Cavity Ring Down) and CEA (Cavity Enhanced Absorption) • Topic 7: The Paul cavity
Objectives	By practical, research-oriented work the students acquire the necessary experimental skills and technical understanding to conduct fieldwork and apply the laboratory techniques of environmental physics. The experience gained in this course enables them to assess and choose experimental methods in order to independently tackle practical problems and develop experimental strategies in their own research projects.
Module parts and teachings methods	Field- and laboratory studies on different topics of Environmental Physics (1LP/CP per topic; see below)
Necessary and useful knowledge	• content of MKEP4 • to be announced by lecturer
Specialities	experimental laboratory and field work
Usability	
Form of testing and examination	oral examination
Term	Winter semester/Summer semester
Duration	1 semester

3.7 Medical Physics

Table 3.7.1: Specialization Medical Physics

Module code	Module	LP/CP	Term
MVMP1	Medical Physics 1	6	WiSe
MVMP2	Medical Physics 2	6	SuSe

Table 3.7.2: Specialization Medical Physics; Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	The Physics and Application of Hadron Therapy	2	WiSe
MVSpec	Advanced Biological Models in Radio Therapy	2	WiSe/SuSe
MVSem	Advanced Seminar on Medical Physics	6	WiSe/SuSe
MVRS	Research Seminar on special topics of Medical Physics	2	WiSe/SuSe
MVJC	Journal Club on Medical Physics	2	WiSe/SuSe

Table 3.7.3 MSc Model study plan "Medical Physics"

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Particle Physics (8 CP MKEP1) Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3)		Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 12 CP + 6 P = 18 CP			
	Medical Physics I (6 CP MVMP1)	Medical Physics II (6 CP MVMP2)		
		Oral examination 6 CP		
Options	Specialized lectures on Medical Physics (2 CP MVSpec)	Specialized lectures on Medical Physics (2 CP MVSpec) Journal Club on Medical Physics (2 CP MVSpec)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.7.4 MSc Model study plan "Medical Physics "

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed matter physics (8 CP MKEP2) Environmental Physics (8 CP MKEP4)		Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 12 CP + 6 P = 18CP			
	Medical Physics II (6 CP MVMP2)	Medical Physics I (6 CP MVMP1)		
		Oral examination 6 CP		
Options	Specialized lectures on Medical Physics (2 CP MVSpec)	Specialized lectures on Medical Physics (2 CP MVSpec) Journal Club on Medical Physics (2 CP MVSpec)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVMP1	Course title: Medical Physics 1
Type	Lecture with exercises
Language	English
Credit points	6
Workload	180 h
Contents	• Production of x-rays • Basics of imaging physics, planar x-ray imaging • Computer tomography (CT), technical developments, CT Radon transformation and image reconstruction • Basics of radiation therapy: radiation fields and dose, foundations of radiobiology • Dose calculation methods for photon and hadron beams • Measurement of dose: detectors and concepts • New concepts in radiation therapy: IMRT, Inverse planning, IGRT
Objectives	After successful finishing of the module • the students will have detailed knowledge of underlying physics and biology of imaging with x-rays, • the students will have gained a deep understanding of the underlying physics of radiotherapy with high energy photon beams, • the students will have obtained proticiency in the unterlying physics of radiotherapy with hadron beams.
Module parts and teachings methods	• Lecture on "Basics of x-ray imaging and radiation therapy" (4 hours/week) • Exercise (2 hour/week)
Necessary and useful knowledge	• basics on electromagnetic interactions and fourier transformations • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Winter semester
Duration	1 semester

Code: MVMP2	Course title: Medical Physics 2
Type	Lecture with exercises
Language	English
Credit points	6
Workload	180 h
Contents	• Positron emission tomography (PET), production of β+–emitters, measurement techniques, image reconstruction, consideration of applied doses • Sonography • Introduction into major biochemical processes • Modern high–resolution techniques for determination of molecular and physiological parameters of cells and tissue • Disposition kinetics, pharmacokinetic modelling • Nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR) • High–resolution NMR spectroscopy • Magnetic resonance imaging (MRI): k–space sampling techniques, fast MRI, functional MRI, spectroscopic imaging • Detection of weak signals, hyperpolarisation • Data analysis in diagnostic imaging, image reconstruction and segmentation
Objectives	After completing this module, the students will have a complete and comprehensive overview of morphological and physiological imaging and spin– and radioactive–tracer techniques. They understand the underlying physical principles, and are able assess their biological application and impact.
Module parts and teachings methods	• Lecture on “Medical Physics 2” (4 hours/week) • Exercise (2 hour/week)
Necessary and useful knowledge	• detector physics, rf-electronics, image processing, basics of biochemistry. • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

3.8 Particle Physics

Table 3.8.1: Specialization Particle Physics

Module code	Module	LP/CP	Term
MVHE1	Advanced Topics in Particle Physics	4	WiSe/SuSe
MVHE2	Physics of Particle Detectors	4	SuSe
MVHE3	Standard Model of Particle Physics	8	SuSe
MVPSI	Advanced Particle Physics Project at the Paul Scherrer Institut. Module cannot be selected as a module for MVMod!	8	WiSe/SuSe

Table 3.8.2: Specialization Particle Physics; Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	Physics at the LHC	2	WiSe/SuSe
MVSpec	New Physics Beyond the Standard Model	2	WiSe/SuSe
MVSpec	Statistical Methods in Particle Physics	4	WiSe/SuSe
MVSpec	Accelerator Physics	4	WiSe
MVSem	Advanced Seminar on Particle Physics	6	WiSe/SuSe
MVRS	Research Seminar on special topics of Particle Physics	2	WiSe/SuSe
MVJC	Journal Club on Particle Physics	2	WiSe/SuSe

Table 3.8.3 MSc Model study plan "Particle Physics"

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Particle Physics (8 CP MKEP1) Theoretical Statistical Physics (8 CP MKTP1))		Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 16 CP + 6 P = 22 CP			
	Advanced Topics in Particle Physics (4 CP MVHE1)	Physics of Particle Detectors (4 CP MVHE2)		
		Oral examination 6 CP		
Options	Quantum Field Theory (8 CP MVTheo1)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.8.4 MSc Model study plan "Particle Physics "

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed Matter Physics (8 CP MKEP2)	Quantum Field Theory (8 CP MVTP4)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced seminar (6 CP MVSem)		
	MVMod: 16 CP + 6 P = 22 CP			
	Standard Model in Particle Physics (8 CP MVHE3) Physics of Particle Detectors (4 CP MVHE2)	Particle Physics (8 CP MKEP1)		
		Oral examination 6 CP		
Options	Specialized Lecture on Particle Physics (2CP MVSpec)	Journal Club on Particle Physics 2 CP MVJC)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVHE1	**Course title: Advanced Topics in Particle Physics**
Type	Lecture and Journal Club
Language	English
Credit points	4
Workload	120 h
Contents	Selected experimental research topics in particle physics. Possible topics are: • Test of Quantum Electrodynamics • Strong Interactions and Quantum Chromodynamics • Nucleon Physics • Electro-weak unification and symmetry breaking • Flavor Physics and CP Violation • Physics beyond the Standard Model • Astroparticle physics • Particle physics and cosmology
Objectives	After completing this course students • have deepened their knowledge and understanding of current research topics in particle physics, • have a profound understanding of the motivation and methods of modern particle physics experiments, • have enhanced their capabilities to understand scientific articles.
Module parts and teachings methods	• Introductory lecture to actual research field in particle physics (2 hours/week) • Journal Club where on the basis of recent publications details of a particular research area are discussed (1 hour/week)
Necessary and useful knowledge	• content of PEP5 (Bachelor), MKEP1 (Master) • to be announced by lecturer
Specialities	Journal Club to discuss actual research topics
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Winter semester/Summer semester
Duration	1 semester

Code: MVHE2	Course title: Physics of Particle Detectors
Type	Lecture, tutorial and exercises
Language	English
Credit points	4
Workload	120 h
Contents	Focus of the lecture is the physics and the layout of detector components used in modern particle physics experiments. Topics are • Interaction of particles with matter • Scintillators and ToF detectors • Gas detectors • Silicon detectors • Calorimeters • Detector for particle identification • Large detector systems
Objectives	After completion of the course the student has gained basic knowledge about interactions of particles with matter, the physics of particle detectors, their working principles, and their applications in experiments.
Module parts and teachings methods	• Introductory lecture into the physics and the technical realization of particle detectors (2 hours/week) • Journal Club where on the basis of recent publications details of a particular research area are discussed (1 hour/week)
Necessary and useful knowledge	• content of PEP4, PEP5, PTP4 • announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

Code: MVHE3	Course title: Standard Model of Particle Physics
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	Theoretical and experimental foundations of the Standard Model (SM) of particle physics on an advanced level. The lecture includes the main building blocks of the Standard Model: QED, weak interactions, gauge symmetries, electroweak symmetry breaking and Higgs mechanism, Flavor Physics, QCD. The lectures are given by a theoretician and experimentalist.
Objectives	Upon completion of this course the student has gained advanced knowledge about the Standard Model of Particle Physics including its mathematical framework based on relativistic quantum field theory, with emphasis on the interplay of experimental results and theoretical developments. The student can formulate the Standard Model and is capable to calculate particle processes using perturbation theory.
Module parts and teachings methods	• Lecture on “Standard Model of Particle Physics” (4 hours/week) • Exercises with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP5 (Bachelor) or MKEP1 (Master), PTP4 (Bachelor), MKTP1 (Master) • to be announced by lecturer
Specialities	exercises with homework.
Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

Code: MVPSI	**Course title: Advanced Particle Physics Project at the Paul Scherrer Institut**
Type	Lecture and laboratory course
Language	English
Credit points	8
Workload	240 h
Contents	• Lectures about particle physics, detectors, electronics, data acquisition, computing and data analysis • Planning, preparation, construction and commissioning of a particle physics experiment • Operation and data taking • Data Analysis and Interpretation of results
Objectives	The student has gained theoretical understanding and practical experience in performing a particle physics experiment using particle beams. This includes the planning, construction, commissioning, operation, and data analysis.
Module parts and teachings methods	• Introduction to the experiment with Lectures (block course) • Practical course (block course)
Necessary and useful knowledge	• content of PEP5, Introductory Lecture on Experimental Particle Physics and Physics of Particle Detectors (recommended). • to be announced by lecturer.
Specialities	Special Lectures and 'hands on' sessions. Limited number of participants. Bachelor students may account for this module as WPProj. This modul cannot be selected as MVMod module.
Usability	
Form of testing and examination	written final report
Term	Winter semester/Summer semester
Duration	1 semester

3.9 Theoretical Physics

Table 3.9.1: Specialization Theoretical Physics

Module code	Module	LP/CP	Term
MVTheo1	Advanced Quantum Field Theory (QFT 2)	8	SuSe
MVTheo2	Condensed Matter Theory	8	WiSe

Table 3.9.2: Specialization Theoretical Physics; Specialised lectures and seminars

[The lectures and seminars listed here will be offered on an irregular basis]

Module code	Module	LP/CP	Term
MVSpec	String Theory	4-8	WiSe/SuSe
MVSpec	Supersymmetry and Supergravity	4-8	WiSe/SuSe
MVSpec	Gauge Theories, QCD	4-8	WiSe/SuSe
MVSpec	Physics beyond the Standard Model	4-8	WiSe/SuSe
MVSpec	Special Topics in Field Theory	4	WiSe/SuSe
MVSem	Advanced Seminar on Theoretical Physics	6	WiSe/SuSe
MVRS	Research Seminar on special topics of Theoretical Physics	2	WiSe/SuSe
MVJC	Journal Club on Theoretical Physics	2	WiSe/SuSe

Table 3.9.3 MSc Model study plan „Theoretical Physics (Particle Physics) “

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Particle Physics (8 CP MKEP1) Quantum Field Theory (8CP MKTP4)		Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 16CP + 6 P = 22 CP			
		Advanced Quantum Field Theory (8CP MVTheo1) Standard Model of Particle Physics (8CP MVHE3)		
		Oral examination 6 CP		
Options	Advanced Lecture on Special Topics (4CP MVSpec)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.9.4 MSc Model study plan „Theoretical Physics (Condensed Matter) “

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Theoretical Statistical Physics (8 CP MKTP1)	Condensed matter physics (8 CP MKEP2)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 16CP + 6 P = 22 CP			
	Quantum Field Theory (8CP MKTP4)	Condensed Matter Theory (8 CP MVTheo2)		
		Oral examination 6 CP		
Options	Advanced Lecture on Special Topics (4CP MVSpec)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.9.5 MSc Model study plan „Theoretical Physics (String Theory) "

[Beginning: winter semester]

<table>
<tr><th>Study block</th><th>1st Semester</th><th>2nd Semester</th><th>3rd Semester</th><th>4th Semester</th></tr>
<tr><td>Core courses & research modules</td><td>Particle Physics
(8 CP MKEP1)

Quantum Field Theory
(8CP MKTP4)</td><td></td><td>Scientific Specialization
(15 CP MFS)
Methods and Project Planning
(15 CP MFP)</td><td>Master Thesis
(30 CP MFA)</td></tr>
<tr><td rowspan="4">Specialization</td><td></td><td>Advanced Seminar
(6 CP MVSem)</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td colspan="2">MVMod: 16CP + 6 P = 22 CP</td></tr>
<tr><td rowspan="2">String Theory
(8 CP MVSpec)</td><td>Supersymmetry / Supergravity
(MVSpec)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td></td><td>Advanced Quantum Field Theory (8 CP MVTheo1)</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.</td></tr>
<tr><td>Total CPs</td><td colspan="2">min. 60 CP</td><td>30 CP</td><td>30 CP</td></tr>
</table>

Code: MVTheo1	**Course title: Advanced Quantum Field Theory (QFT 2)**
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Effective action • Symmetries and conservation laws • Gauge theories: QED, QCD, QFT, quantized • Feynman rules in Lorentz covariant gauges • Renormalization in Gauge theories • One-loop QED • Spontaneous symmetry breaking and Higgs mechanism • Renormalization groups, Wilson renormalization, lattice gauge theory
Objectives	After completing the course the students • have a thorough knowledge and understanding of the regularisation and renormalisation programme in Φ^4-theory, of renormalisation in QED and non-abelian gauge theories (1-loop order), of the effective action and the modern renormalisation group approach, • have acquired the necessary mathematical knowledge and competence for an in-depth understanding of this research field, • have advanced competence in the fields of theoretical physics covered by this course, i.e. the ability to analyze physical phenomena using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to interpret the solutions physically and communicate them efficiently, • are able to broaden their knowledge and competence in this field of theoretical physics on their own by a systematical study of the literature.
Module parts and teachings methods	• Lecture on “Quantum Field Theory 2” (4 hours/week) • Exercise with homework (2 hours/week)
Necessary and useful knowledge	• content of PEP3, PTP4, MVTheo1, MKTP1 • announced by lecturer
Specialities	exercises with homework
Usability	
Form of testing and examination	defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

Code: MVTheo2	Course title: Condensed Matter Theory
Type	Lecture with exercises
Language	English
Credit points	8
Workload	240 h
Contents	• Introductory materials: bosons, fermions and second quantisation • Green's functions approach • Exactly solvable problems: potential scattering, Luttinger liquids etc. • Theory of quantum fluids, BCS theory of superconductivity • Quantum impurity problems: Kondo effect, Anderson model, renormalisation group approach Depending on the lecturer more weight will be given to solid state theories or to soft matter.
Objectives	After completing the course the students • have a thorough knowledge and understanding, of the nowadays 'traditional' diagrammatic technique and the problems solved by this technique, including Landau's theory of quantum liquids and BCS theory of superconductivity, • of advanced non-perturbative approaches such as renormalization group transformations, bosonisation and Bethe Ansatz and there application to examples of quantum impurity problems such as potential scattering in Luttinger liquids, inter-edge tunneling in fractional quantum Hall probes and Kondo effect in metals and mesoscopic quantum dots, • have acquired the necessary mathematical knowledge and competence for an in-depth understanding of this research field, • have advanced competence in the fields of theoretical physics covered by this course, i.e. the ability to analyze physical phenomena using the acquired concepts and techniques, to formulate models and find solutions to specific problems, and to interpret the solutions physically and communicate them efficiently, • are able to broaden their knowledge and competence in this field of theoretical physics on their own by a systematical study of the literature.
Module parts and teachings methods	• Lecture on Condensed Matter Theory (4 hours/week) • Exercise (2 hour/week)
Necessary and useful knowledge	• content of PTP4, MKTP1, Complex Analysis • to be announced by lecturer
Specialities	exercises with homework

Usability	
Form of testing and examination	to be defined by lecturer before beginning of course
Term	Summer semester
Duration	1 semester

4. Options

To complete their study programme of the first year and to acquire the minimum of 60 CP students can select subjects from an adjacent subject area, or subjects from the field of „transferable skills“. Modules from the core physics programme and from the specialization programme can also be selected. In addition, modules offered by other departments can be chosen. These are subjects from the fields of:

Biology
Chemistry
Geological Sciences
Computer Science
Physics of Imaging
Mathematics
Philosophy
Physiology
Economics

The objective of the options sector is to enable students to choose subjects in areas other than physics, in order to be prepared to be able to perform cutting edge research in interdisciplinary fields in which physics plays a major role or in applied physics. Subjects taken in this sector may as a rule run over two semesters.

Other subjects not listed explicitly in this chapter may also be considered suitable for the options sector of the master degree; in such cases, permission must be requested explicitly by applying to the Master Examination Commission (MEC).

In addition to the above mentioned fields, modules can be chosen from the range of „transferable skills“ on offer. It is recommended that students obtain 6 CP through successful completion of such courses. In the field of „Transferable Skills“, one refers to subjects, which are essential for success in today’s work market, both within and outside of the academic sector. These types of competencies are divided into three categories, „personal key competences“, „professional key competences” as well as „specific additional technical competences“. In the table below, some of the most commonly chosen modules in the field of „Transferable Skills“ and Computer Science are listed. Those modules are also offered to Bachelor students and can be found in detail in the BSc Module Manual.

Table 4.1: Personal key competences

Module code	Module	LP/CP	Term
UKTutor	Special training for basis course tutors	6	SuSe/WiSe
UKPVD	Course on teaching and learning (didactics)	1	SuSe/WiSe
UKPVP	Course on teaching and learning (practical)	2	SuSe/WiSe

Table 4.2: Professional key competences

Module code	Module	LP/CP	Term
UKBI1	Block course: Programming in C++	1	SuSe/WiSe
UKBI2	Block course: Data analysis	1	SuSe/WiSe

Table 4.3: Specific additional technical competences

Module code	Module	LP/CP	Term
General technical competences			
UKNum	Practical Course: Numerical Methods	3	WiSe
UKSta	Practical Course: Statistical Methods	3	SuSe
Additional technical competences in mathematics			
UKMath1	Higher course in analysis	8	WiSe
UKMath2	Introduction to numerical calculations	8	SuSe
UKMath3	Partial differential equations	8	
Additional competences in scientific computation			
UKWR1	Scientific computation 1	8	WiSe
UKWR2	Introduction to computer physics	6	SuSe
Additional competences in electronics			
UKEL1	Electronics and electronic laboratory course	7	WiSe
UKEL2	Microelectronics and electronic laboratory course	7	WiSe
Additional competences in computer science			
UKInf1 (IPR)	Introduction to applied computation	7	WiSe
UKInf2	Introduction to technical computation	7	SuSe
UKInf3	Computer science laboratory	6	WiSe/SuSe
UKInf4 (IAD)	Algorithms and data structures	7	SuSe
UKInf5 (IBN)	Operating systems and networks	7	WiSe
UKInf6 (IDB)	Introduction to databases	4	SuSe
UKInf7 (ISE)	Introduction to software engineering	4	WiSe
UKInf8 (ITH)	Introduction to theoretical computer science	7	SuSe
Additional competences in chemistry			
UKChe	General chemistry	12	SuSe/WiSe
Additional competences in biology			
UKBio	Fundamentals of cellular and molecular biology	8	WiSe
Additional competences in economics			
UKPö1a	Introduction to political economics	8	WiSe
UKPö1b	Corporate Governance	8	WiSe

UKPö2a	Macro economics	8	SuSe
Additional competences in physiology			
UKPhy 1	Introduction to physiology and medical biophysics	4	SuSe
UKPhy 2	Cellular and molecular foundations of medical biophysics	4	WiSe

Table 4.4: Modules in Computer Science

Module code	Module	LP/CP	Term
MWInf1	Parallel Computer Architectures	8	SuSe
MWInf2	Digital Circuit Technology	8	WiSe
MWInf3	Design of VLSI Circuits using VHDL	4	SuSe
MWInf4	Embedded Systems	4	WiSe
MWInf5	Physics of Imaging	4	WiSe

The detailed description of the modules mentioned in Table 4.4 can be found in the B.Sc. Applied Computational Science module manual.

5. Mandatory research phase modules

The one year research phase comprises the following mandatory modules:

Module code	Module	LP/CP	Term
MFS	Scientific Specialization	15	WiSe/SuSe
MFP	Methods and Project Planning	15	WiSe/SuSe
MFA	Master Thesis	30	WiSe/SuSe

The module Scientific “Specialization“ introduces to a specific research field and might comprise specified lectures, seminars or journal clubs. The module “Methods and Project Planning” prepares the specific research envisaged during the Master Thesis

Code: MFS	Course title: Scientific Specialization
Type	Practice Course
Language	English
Credit points	15
Workload	450 h
Contents	• The content of the module is defined together with the supervisor and will vary depending on the chosen research field in which the master thesis is planned. • In addition to the work within the research group may comprise specified lectures, seminars or journal clubs as well as a substantial part of self-study.
Objectives	Upon completion of this module, the student has obtained advanced knowledge in the research field of the planned master thesis.
Module parts and teachings methods	• Preparation Course Master Thesis
Necessary and useful knowledge	• Prerequisites: Successful termination of MVMod. • In justified cases and on request, the examination of the module MVMod can be passed in the course of the module MFS. The request has to be approved by the Prüfungsausschuss.
Specialities	Work within a research group under supervision of the group leader; to pass this module, the student has to be part of a research group.
Usability	
Form of testing and examination	Oral report on the content of the module
Term	Winter semester/Summer semester
Duration	1 semester

Code: MFP	Course title: Methods and Project Planning
Type	Practice Course
Language	English
Credit points	15
Workload	450 h
Contents	• The content of the module is defined together with the supervisor and will vary depending on the chosen research field in which the master thesis is planned. • In addition to the work within the research group may comprise specified lectures, seminars or journal clubs as well as a substantial part of self-study.
Objectives	Upon completion of this course, the student is well prepared for the master thesis
Module parts and teachings methods	Work within a research group under supervision of the group leader; to pass this module, the student has to be part of a research group. Upon completion of this course, the student is well prepared for the master thesis.
Necessary and useful knowledge	• Prerequisites are MFS and advanced knowledge in research area in which master thesis is planned. • Recommended literature is suggested by supervisor.
Specialities	Work within a research group under supervision of the group leader
Usability	
Form of testing and examination	Oral report on the content of the module
Term	Winter semester/Summer semester
Duration	1 semester

Code: MFA	**Course title: Master Thesis**
Type	Practice Course
Language	English
Credit points	30
Workload	900 h
Contents	Research work on a specific physics topic.
Objectives	After completing the master thesis, the student is familiar with scientific research and well positioned to pursue a successful career as physicist in academia or industry.
Module parts and teachings methods	• Master Thesis
Necessary and useful knowledge	• Prerequisites are: MFS and MFP and advanced knowledge on the research area of the master thesis • Useful literature is suggested by supervisor.
Specialities	work within a research group under supervision of the group leader.
Usability	
Form of testing and examination	written master thesis.
Term	Winter semester/Summer semester
Duration	

6. Model study plans

As a large fraction of the courses taken can be freely selected, there are many possible combinations that may be considered in constructing the coursework sector of the master degree. Students should inform themselves of the options at an early stage in planning their degree. The master degree in physics can be extremely focused or set out with a wide education.

Examples for a wide general education in physics with focus on experimental physics are given in Tables 6.1 and 6.2 (model study plans „Experimental Physics“). Detailed recommendations, depending on the field of specialization and the beginning of the studies, winter or summer semester respectively, are given in sections 3.1 to 3.9.

Table 6.1 MSc Model study plan “Experimental Physics”

[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Particle Physics (8 CP MKEP1)	Condensed Matter Physics (8 CP MKEP2)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization		Advanced Seminar (6 CP MVSem)		
	MVMod: 14 CP + 6 P = 20 CP			
	Advanced Lecture on Special Topics (6CP MVSpec)	Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3)		
		Oral examination 6 CP		
Options	Theoretical Statistical Physics (8 CP MKTP1)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

Table 6.2 MSc Model study plan “Experimental Physics”

[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Condensed Matter Physics (8 CP MKEP2)	Particle Physics (8 CP MKEP1)	Scientific Specialization (15 CP MFS) Methods and Project Planning (15 CP MFP)	Master Thesis (30 CP MFA)
Specialization	Advanced Seminar (6 CP MVSem)			
	MVMod: 14 CP + 6 P = 20 CP			
	Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3)	Advanced Lecture on Special Topics (6 CP MVSpec)		
		Oral examination 6 CP		
Options		Theoretical Statistical Physics (8 CP MKTP1)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

7. Classification

Module code	Meaning
M*****	Masterlevel module
MK***	Masterlevel core module
MV******	Masterlevel specialisation module
MF*	Masterlevel reserch phase module
MKTP#	Masterlevel core module in theoretical physics
MKEP#	Masterlevel core module in experimental physics
MVSem	Masterlevel mandatory advanced seminar
MVMod	Masterlevel specialization module
MVSpec	Masterlevel advanced lecture on special topic
MVRS	Masterlevel optional research seminar
MVJC	Masterlevel journal club
MVProj	Masterlevel project practical
MVPSI	Masterlevel advanced particle physics project at the Paul Scherrer Institut
MVAstro#	Masterlevel specialisation module in astronomy or astrophysics
MVAMO#	Masterlevel specialisation module in atomic, molecular and optical physics
MVBP#	Masterlevel specialisation module in biophysics
MVCMP#	Masterlevel specialisation module in condensed matter physics
MVEnv#	Masterlevel specialisation module in environmental physics
MVMP#	Masterlevel specialisation module in medical physics
MVHE#	Masterlevel specialisation module in Advanced Topics in Particle Physics
MVTheo#	Masterlevel specialisation module in theoretical physics
MVComp#	Masterlevel specialisation module in computational physics
MFS	Scientific Specialization
MFP	Methods and Project Planning
MFA	Master Thesis

Module code	Course Titel	Module type
MKTP1	Theoretical Statistical Physics	Lecture with exercises
MKTP2	Theoretical Astrophysics	Lecture with exercises
MKTP3	General Relativity	Lecture with exercises
MKTP4	Quantum Field Theory (QFT1)	Lecture with exercises
MKTP5	Cosmology	Lecture with exercises
MKEP1	Particle Physics	Lecture with exercises
MKEP2	Condensed Matter Physics	Lecture with exercises, seminar
MKEP3	Advanced Atomic, Molecular and Optical Physics	Lecture with exercises
MKEP4	Environmental Physics	Lecture with exercises

MKEP5	Astronomical Techniques	Lecture with exercises
MVSem	Mandatory Advanced Seminar	Mandatory Seminar
MVMod	Specialization Module	Lectures and tutorials
MVSpec	Advanced Lecture on Special Topic	Lecture
MVRS	Research Seminar (optional)	Seminar
MVJC	Journal Club	Seminar
MVProj	Project Practical	Practice Course
MVAstro0	Introduction to Astronomy and Astrophysics	Lecture with exercises
MVAstro1	Astronomical Techniques (Compact)	Lecture and laboratory course
MVAstro2	Stellar Astronomy and Astrophysics	Lecture with exercises, seminar
MVAstro3	Galactic and Extragalactic Astronomy	Lecture with exercises, seminar
MVAstro4	Cosmology (compact)	Lecture with exercises
MVAMO1	Experimental Optics and Photonics	Lecture with exercises
MVAMO2	Advanced Quantum Theory	Lecture with exercises
MVAMO3	Experimental Methods in Atomic, Molecular and Optical Physics	Lecture with exercises
MVBP1	Experimental Biophysics	Lecture with exercises
MVBP2	Theoretical Biophysics	Lecture with exercises
MVCMP1	Low Temperature Physics	Lecture with exercises
MVCMP2	Surfaces and Nanostructures	Lecture with exercises; visits to laboratory
MVCMP3	Electronic Correlations and Magnetism	Lecture with exercises
MVEnv1	Atmospheric Physics	Lecture with exercises
MVEnv2	Physics of Terrestrial Systems	Lecture with exercises
MVEnv3	Physics of Aquatic Systems	Lecture with exercises
MVEnv4	Physics of Climate	Lecture with exercises
MVEnv5	Practical Environmental Physics	Practical and laboratory course
MVMP1	Medical Physics 1	Lecture with exercises
MVMP2	Medical Physics 2	Lecture with exercises
MVHE1	Advanced Topics in Particle Physics	Lecture and Journal Club
MVHE2	Physics of Particle Detectors	Lecture, tutorial and exercises
MVHE3	Standard Model of Particle Physics	Lecture with exercises
MVPSI	Advanced Particle Physics Project at the Paul Scherrer Institut	Lecture and laboratory course
MVTheo1	Advanced Quantum Field Theory (QFT 2)	Lecture with exercises
MVTheo2	Condensed Matter Theory	Lecture with exercises
MVComp1	Fundamental of Simulation Methods	Lecture with exercises
MVComp2	Computational Statistics and Data Analysis	Lecture with exercises
MFS	Scientific Specialization	Practice Course
MFP	Methods and Project Planning	Practice Course
MFA	Master Thesis	Practice Course