Master of Science in Physics (MSc Physik)

Description of the course modules.

Version 2013.2/v5

Versions:

Version 2011.v1	Adaptation to the MSc manual to the MSc PO from June 2011: Description of the master program Description of the specialization part Adaptation of model study plans Additional changes: Module descriptions condensed matter & organic electronics Module descriptions astronomy
Version 2012.1/v2	Sprungadressen für Barriere-Freiheit Study plan Medical Physics Correction of module acronyms MVTheo1,2 in study plans
Version 2012.2/v3	Credit points for the module MVCMP1 changed from 6 to 8 CPs. MKEP2 only SomSem. Study plan changed accordingly. MFS: Possibility to pass the examination of MVMOD in the course of the module MFS.
Version 2013.1/v1	Specialisation Computational Physics included
Version 2013.2/v1	CP(MVEnv1-4) = 4, Model study plans adjusted
Version 2013.2/v2	New MKEP5 Astronomical Techniques
Version 2013.2/v3	New MVEnv4 Physics of Climate
Version 2013.2/v4	New MVProj Project Practicle

Contents

1.The master course in physics

The research oriented master programme in physics builds on the bachelor degree and is designed to provide a deeper, more specialised knowledge of a specific field of physics, as well as to provide a general knowledge of methods in physics. Students may, during the course of their master study, also obtain a deeper insight into other neighbouring fields of physics, depending on the choice of modules taken. In addition, the master degree is designed to prepare students to enter into a doctoral programme. To this end, a comprehensive teaching programme is available in order to enable students to reach this high degree of specialization either in a chosen, specific area of physics, or within an interdisciplinary area of research. The master degree in physics at the Department of Physics and Astronomy at the University of Heidelberg is in particular noted for the great flexibility and freedom of choice available to students in selecting the direction of study. This enables master students to follow their own specific interests.

The first two semesters (first year, specialization phase) of the master programme serve to further 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 credits points (CP) assigned to each of these sectors. 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, and16 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 ... 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 in Chapter 5 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) Particle Physics	MKEP1	8
(6) Condensed Matter Physics	MKEP2	8
(7) Advanced Atomic, Molecular and Optical Physics	MKEP3	8
(8) Environmental Physics	MKEP4	8
(9) Astronomical Techniques	MKEP5	8
Total number of credit points – core courses		16
Specialization in physics (mandatory)		
Mandatory seminar	MVSem	6
Specialization module: Lectures, tutorials,, seminars (12...16 CP) Oral examination (6 CP)	MVMod	18…22
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	WS
MKTP2	Theoretical Astrophysics	8	WS
MKTP3	General Relativity	8	SS
MKTP4	Quantum Field Theory	8	WS
MKEP1	Particle Physics	8	WS/SS
MKEP2	Condensed Matter Physics	8	SS[1]
MKEP3	Advanced Atomic, Molecular and Optical Physics	8	WS
MKEP4	Environmental Physics	8	WS/SS
MKEP5	Astronomical Techniques	8	SS

[1] The lecture will be given in WS 2012/13.

<table>
<tr><td colspan="2">Code: MKTP1</td><td colspan="3">Course Title: Theoretical Statistical Physics</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 8</td><td>Workload: 240 h</td><td>Teaching Hours:
3/week</td><td>Mode:
WPM</td><td>Term:
WS</td></tr>
<tr><td colspan="5">
Module Parts:

• Lecture on “Statistical Physics” (4 hours/week)
• Exercise with homework (2 hours/week)

Module 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.

Objective: Firm grasp of the laws of thermodynamics and of the description of ensembles in the framework of classical and quantum statistics. Knowledge of applications to phase transitions and condensed matter, plasma and astrophysics.
</td></tr>
<tr><td colspan="5">
Necessary/useful Knowledge: Content of PEP3, PTP4

Recommended Literature: announced by lecturer

Specialties: Exercises with homework
</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Usually a 2-3 hours written examination.</td></tr>
</table>

Code: MKTP2		**Course Title**: Theoretical Astrophysics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload**: 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on Theoretical Astrophysics (4 hours/week)
- Exercise with homework (2 hours/week)

Module Contents:

- Radiative processes (9): Macroscopic radiation measurements; emission, absorption and scattering, radiative transfer; Bremsstrahlung and synchrotron radiation; ionization and recombination; spectra
- Hydrodynamics (9): Basics and equations of motion; ideal and viscous fluids and currents; sound waves, supersonic currents and shock waves; instabilities, convection and turbulence
- Plasma physics (6): 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 (6): Relaxation; Jeans equations and Jeans theorem; tensor-virial theorem; equilibrium and stability of self-gravitating systems; dynamical friction; Fokker-Planck approximation

Objective: Introduction to the fields of theoretical physics, which are of special importance for theoretical astrophysics, and which are not covered by the course lectures of theoretical physics; target audience are students with special interest in astronomy and astrophysics or in theoretical physics

Necessary/useful Knowledge: Content of PTP1, PTP2, PTP3, PTP4, WPAstro

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKTP3		**Course Title**: General Relativity		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: SS

Module Parts:

- Lecture on “General Relativity” (4 hours/week)
- Exercise with homework (2 hours/week)

Module 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

Objective: To have a firm command of Einstein’s theory of General Relativity including the necessary tools from differential geometry and applications such as black holes, gravitational radiation and cosmology.

Necessary/useful Knowledge: Content of PTP1, PTP2, PTP3, PTP4

Recommended Literature: announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKTP4		**Course Title**: Quantum Field Theory (QFT1)		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on "Quantum Field Theory 1" (4 hours/week)
- Exercise with homework (2 hours/week)

Module 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

Objective: To have a firm command of relativistic field equations and the theory of free quantum fields. The students should 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.

Necessary/useful Knowledge: Content of PEP3, PTP4, MKTP1

Recommended Literature: announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKEP1		**Course Title**: Particle Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Introductory Lecture on Experimental Particle Physics (4 hours/week)
• Exercises with homework (2 hours/week)

Module 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

Objective: Overview of the experimental foundation of modern particle physics and introduction into today's main experimental questions. The tutorials provide the possibility for further discussions.

Necessary/useful Knowledge: Content of PEP4, PEP5, PTP4

Literature: announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKEP2		**Course Title**: Condensed Matter Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises, seminar		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Lecture on Condensed Matter Physics (4 hours/week)
• Exercise with homework (2 hours/week)

Module 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)

Objective: Introduction to the fundamentals of condensed matter physics.

Necessary/useful Knowledge: Content of PEP1-PEP5

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKEP3		**Course Title**: Advanced Atomic, Molecular and Optical Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload**: 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on Advanced Atomic, Molecular and Optical Physics (4 hours/week)
- Exercise with homework (2 hours/week)

Module Contents:

- Review of one-electron atomic systems
- Two- and many-electron atomic systems
- Electronic structure and binding in molecules
- Atoms and molecules in static external fields
- Interaction with radiation
- Atomic collisions and radiation less processes
- Particle preparation, particle detection
- Sources of electromagnetic radiation
- Atomic and molecular spectroscopy
- Cooling and trapping

Objective: Experimental and theoretical basics of modern atomic, molecular and optical physics.

Necessary/useful Knowledge: Content PEP1-PEP3

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKEP4		**Course Title**: Environmental Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload**: 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Lecture on “Environmental Physics” (4 hours/week)
• Exercise with homework (2 hours/week)

Module 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

Objective: Fundamental understanding of the physical processes and interactions of the Earth system

Necessary/useful Knowledge: Content of PEP1-PEP3

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: Usually a 2-3 hours written examination.

Code: MKEP5		**Course Title**: Astronomical Techniques		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: SS

Module Parts:
- Lecture on "Astronomical Techniques" with exercises (4 hours/week)
- Exercise with homework (2 hours / week)

Module 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.

Objective: Concepts, technologies, and physical principles of modern observational techniques, along with their scientific applications.

Necessary/useful Knowledge: **:** Knowledge of the introductory astronomy lectures (MVAstro0 or WPAstro); basic knowledge on 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.

Form of Testing and Examination: Usually a 2-3 hours written examination.

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 to 12...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 in this section 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 orient their choice 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 the following sections of this chapter, 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 section. Note, however, that not all modules will be offered on a regular basis. In particular, the Specialization courses, seminars and journal clubs on offer 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 possibly 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	WS/SS
MVMod	Specialization module: Specialization courses (12...16 CP) Oral examination (6 CP)	18…22	WS/SS
MVSpec	Advanced Lecture on Special Topics	2-8	WS/SS
MVRS	Research Seminar on special topic (optional)	2	WS/SS
MVJC	Journal Club	2	WS/SS
MVProj	Projecat Practical	4-12	WS/SS

<table>
<tr><td colspan="2">Code: MVSem</td><td colspan="3">Course Title:
Mandatory Advanced Seminar</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Mandatory Seminar</td></tr>
<tr><td>Credit Points: 6</td><td>Workload: 180 h</td><td>Teaching Hours:
2/week</td><td>Mode:
WPM</td><td>Term:
WS/SS</td></tr>
<tr><td colspan="5">Module Parts:

• Advanced Seminar (mandatory)

Module 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.

Objective: Understanding of the intentions and difficulties of modern research in physics or another physics related area; learn how to handle modern literature and how to extract information from present-day physics publications.
Beside the oral presentation of the research topic also is write-up of the presented talk is required.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature: To be announced by lecturer

Specialties: –</td></tr>
<tr><td colspan="5">Form of Testing and Examination:
Presentation and write-up as well as participation in discussions.</td></tr>
</table>

<table>
<tr><td colspan="2">Code: MVMod</td><td colspan="3">Course Title: Specialization Module</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lectures and tutorials</td></tr>
<tr><td>Credit Points:
18…22</td><td>Workload:
540-660 h</td><td>Teaching Hours:
8-12/week</td><td>Mode:
WPM</td><td>Term:
WS/SS</td></tr>
</table>

Module Parts:

- Several modules from a single specialization field selected by the student and totalling to 12...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 used to fulfil the core course requirement of section 2 and if they have not been part of the students bachelor studies.
- Oral examination on the content of the above modules (6 CP). The comprehensive preparation of the examination should emphasis the interconnection of the sub-modules.

Module Contents:

- Special topics on a particular research area. The exact modules can be chosen freely by the student. It is recommended to follow the selection of the corresponding model study plan.

Objective:

- Advanced knowledge about a specific research field

Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature: to be announced by lecturer

Specialties: –

Form of Testing and Examination: The single sub-modules have to be passed individually. The complete module is graded by the oral examination after al sub-modules have been passed.

Code: MVSpec		**Course Title**: Advanced Lecture on Special Topic		
Programme: Master of Science (Physics)		**Type**: Lecture		
Credit Points: 2-8	**Workload:** 60-240 h	**Teaching Hours**: 2-6/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

- Advanced Lecture on Special Topic

Module Contents:

- Special topics on a particular research area

Objective: Advanced knowledge about a specific research field

Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature: to be announced by lecturer

Specialties: –

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVRS		**Course Title**: Research Seminar (optional)		
Programme: Master of Science (Physics)		**Type**: Seminar		
Credit Points: 2	**Workload:** 60 h	**Teaching Hours**: 2/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Advanced Seminar

Module 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.

Objective: Understanding of the intentions and difficulties of modern research in physics or another physics related area; learn how to handle modern literature and how to extract information from present-day physics publications.

Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature: To be announced by lecturer

Specialties: –

Form of Testing and Examination: Presentations and participation in discussions.

Code: MVJC		**Course Title**: Journal Club		
Programme: Master of Science (Physics)		**Type**: Seminar		
Credit Points: 2	**Workload:** 60 h	**Teaching Hours**: 2/week	**Mode**: WPM	**Term**: WS/SS

Module Parts:

- Journal Club

Module 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.

Objective: Understanding of the intentions and difficulties of modern research in physics or another physics related area; learn how to handle modern literature and how to extract information from present-day physics publications.

Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature:

To be announced by lecturer **Specialties**: –

Form of Testing and Examination: Presentation and participation in discussions.

<table>
<tr><td colspan="2">Code: MVProj</td><td colspan="3">Course Title: Project Practical</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Practice Course</td></tr>
<tr><td>Credit Points: 4 - 12</td><td>Workload:
120 h – 360 h</td><td>Teaching Hours:
4/week</td><td>Mode: WM</td><td>Term:
WS/SS</td></tr>
<tr><td colspan="5">Module Parts:
• Project practical in research group; upon request also internships in non-university research institutions or in industry are possible, if supervised by a member of faculty.
• The practical can vary between 4 and 12 CP, the actual contact time in the research group will be discussed with the supervisor. The module can extend over two semesters.

Module Contents:
• 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.

Objective:
• The student will become exposed to scientific conduct.
• He or she will become acquainted with a current research topic.
• He or she will acquire technical skills that will be useful for the later research phase.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: General knowledge about the research field discussed.

Recommended Literature: To be announced by practical supervisor

Specialties: –</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Defined by lecturer before beginning of practical, no grades will be given.</td></tr>
</table>

3.1 Astronomy and Astrophysics

Table 3.1.1: Specialization Astronomy and Astrophysics

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

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	WS/SS
MVSpec	Laboratory Course Astrophysics II	2	WS/SS
MVSpec	Observing the Big Bang	3	WS
MVSem	Advanced Seminar on Astronomy or Astrophysics	6	WS/SS
MVRS	Research Seminar on special topics of astronomy or astrophysics	2	WS/SS
MVJC	Journal Club on Astronomy or Astrophysics	2	WS/SS

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: 12 CP + 6 P = 18 CP			
	Cosmology (MVAstro4 6 CP)	Stellar Astronomy and Astrophysics (MVAstro2 6CP) or Galactic and Extragalactic Astronomy (6 CP MVAstro3)		
		Oral examination 6 CP		
Options		General Relativity (8CP MKTP3)		
	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: 12 CP + 6 P = 18 CP			
	Stellar Astronomy and Astrophysics (MVAstro2 6CP) or Galactic and Extragalactic Astronomy (6 CP MVAstro3)	Cosmology (6 CP MVAstro4)		
		Oral examination 6 CP		
Options	General Relativity (8CP, MKTP3)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Code: MVAstro0	**Course Title:** Introduction to Astronomy
Programme: Master of Science (Physics)	**Type:** Lecture with exercises

Credit Points: 8	**Workload**: 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:
• Lecture on Introduction to Astronomy and Astrophysics with Exercises
(6 hours/day: 3 weeks block course in Sept.)

Module Contents:
Lecture „Introduction to Astronomy and Astrophysics“
• Astronomical basics (4): 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 (5): 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 (3): 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 (3): components, gas dust; ionization and recombination, Stroemgren spheres; heating and cooling; chemical enrichment
• Galaxies (4): 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 (3): optical properties and cluster gas; hydrostatic model; scaling relations; number densities and evolution
• Gravitational lensing (2): Concepts, mass distribution in galaxies and galaxy clusters; cosmological lensing effect
• Large scale distribution of galaxies and gas (3): Structure in the spatial galaxy distribution; redshift effects; biasing; Lyman-α-forest; Gunn-Peterson effect and cosmic reionization
• Cosmological boundary conditions (3): Friedmann-Lemaître models, cosmological standard model; origin and evolution of structures; halos of Dark Matter; Formation of galaxies

Objective: Basic knowledge on Astronomy and Astrophysics; basics on how astronomical data are taken, analysed and interpreted as well as on techniques of astrophysical research.

Necessary/useful Knowledge: Basic knowledge on physics and mathematics. electromagnetic radiation and Fourier theory
Recommended Literature: To be announced by lecturer
Specialties: Block course, exercises with homework, equivalent to BSc-Module parts WPAstro 1+2.

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVAstro1	**Course Title**: Astronomical Techniques (Compact)
Programme: Master of Science (Physics)	**Type**: Lecture and laboratory course

Credit Points: 6	**Workload**: 180 h	**Teaching Hours**: 5 /week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on Observational Methods (2 hours/week)
- Exercise (1 hour / week)
- Laboratory Course (2 hours/week)

Module Contents:
Module Part 1: Lecture „Observational Methods“ (4 LP)

- Optics and telescopes (4): geometrical optics, Fraunhofer diffraction; refracting and reflecting telescopes; construction of telescopes and their properties; imaging errors, aberration and their corrections; structure and mounting of telescopes
- Influence of the atmosphere on astronomical observations (4): Transmission, emission, their wavelength dependence and correction methods; atmospheric turbulence and seeing
- Adaptive and active optics (2): Basics; wave front sensors and correction methods; practical application
- Detectors (3): Principals and construction of CCDs, sensitivity, linearity and stability; read-out methods, charge transfer and accumulation, read-out noise; infrared detectors and arrays
- Imaging, photometry and spectroscopy (2): Reduction and combination of image data; photometric units, filter systems, point spread function, measuring methods and calibration; spectroscopic methods, reduction of spectroscopic data

Module Part 2: Astrophysical Laboratory Course II (2 LP)
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:

- Planetary systems: Discovering methods, properties, observed frequencies;
- Stellar dynamics: Dynamics of stellar systems, mass determinations;
- Galaxy evolution: Morphological properties, stellar populations, intergalactic medium;
- Radiative processes: Thermal, non-thermal, radiative transfer;
- Observational cosmology: Distance determination, quantification of cosmological parameters

Objective: Presentation of modern astronomical telescopes and instruments, their functional properties and limits for students with special interest in astronomy; performing the practical course, solving exercises and presentation of the results.

Necessary/useful Knowledge: Basic knowledge on electromagnetic radiation and Fourier theory; content of “Introduction to Astronomy and Astrophysics I and II” (WPAstro);
Recommended Literature: To be announced by lecturer
Specialties: Exercises; Laboratory course is a 1 week block course; there is a strong overlap with MKEP5 (acceptance of MKEP5 or MVAstro1 is exclusive).

Form of Testing and Examination: defined by lecturer before beginning of course

<table>
<tr><td colspan="2">Code: MVAstro2</td><td colspan="3">Course Title: Stellar Astronomy and Astrophysics</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises, seminar</td></tr>
<tr><td>Credit Points: 6</td><td>Workload: 180 h</td><td>Teaching Hours: 5/week</td><td>Mode: WPM</td><td>Term: SS</td></tr>
</table>

Module Parts:

- 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)

Module Contents:
Module Part 1: Lecture "Stellar Astronomy and Astrophysics" (4 LP)
- 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; detection of the fusion by Neutrinos; growth 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 (2LP)
- Presentations and discussions on actual topics in stellar astronomy and astrophysics

Objective: detailed presentation of the theory of structure and evolution of stars for students with special interest in astronomy and astrophysics

Necessary/useful Knowledge: Content of WPAstro, MKTP2

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVAstro3	**Course Title: Galactic and Extragalactic Astronomy**
Program: Master of Science (Physics)	**Type: Lecture with exercises, seminar**

Credit Points: 6	**Workload**:180 h	**Teaching Hours**: 5/week	**Mode**: WPM	**Term**: SS

Module Parts:

- 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)

Module Content:

Module Part 1: Lecture "Galactic and Extragalactic Astronomy" (4 LP*)*

- 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;
- Spirals and elliptical (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 LP)

- Presentations and discussions on selected topics in galactic and extragalactic astronomy

Objective: Detailed presentation of topics in Galactic and extragalactic astronomy including special galaxy types, satellite missions and surveys, including topics not covered in detail in the lecture (e.g., gamma ray bursts, extragalactic globular cluster systems, baryon acoustic oscillations, etc.).

Necessary/useful Knowledge: content of WPAstro, MKTP2

Recommended Literature: Sparke & Gallagher: "Galaxies in the Universe" (CUP)

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVAstro4		**Course Title**: Cosmology		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises, seminar		
Credit Points: 6	**Workload**: 180 h	**Teaching Hours**: 5/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on “Cosmology” (2 hours/week)
- Exercise (1 hour/week)
- Seminar on Special Topic in “Cosmology” (2 hours/week)

Module Contents:
Module Part 1: Lecture “Cosmology” (4 LP*)*
- Homogeneous and isotropic cosmology (4): Friedmann-Lemaître models, geometry, redshift and dynamics; parameters, distance measures and ages; thermal evolution, freezing out of reactions; primordial nucleo-synthesis and recombination
- Inhomogeneities in the universe (5): Evolution of density and velocity perturbations; power spectra, Zel’dovich approximation and nonlinear evolution; spherical collapse model and extended Press-Schechter formalism
- Early universe (3): Structures in the Cosmic Microwave Background, simplified theory, power spectrum and interpretation; basics of cosmic inflation; accelerated expansion, dark energy and possible cosmological effects
- Late universe (3): Structures in the evolved universe; large scale gas and galaxy distribution, power spectrum and interpretation; gravitational lenses, cosmic shearing and amplification; evolution of the galaxy cluster population

Module Part 2: Seminar (2LP)
- Presentations and discussions on actual topics in cosmology

Objective: Detailed presentation of the cosmological standard model, the cosmological evolution and structure formation for students with special interest in astronomy and astrophysics, in particle astrophysics and in theoretical physics

Necessary/useful Knowledge: Content of WPAstro, MKTP2

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

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	WS
MVAMO2	Advanced Quantum Theory	4	SS
MVAMO3	Experimental Methods in Atomic & Molecular Physics	4	SS

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	WS/SS
MVSpec	Quantum Information	3	WS/SS
MVSpec	Special Topics in Atomic and Molecular Physics	3	WS/SS
MVSpec	Quantum Dynamics and Control	3	WS/SS
MVSpec	Quantum Electrodynamics	3	WS/SS
MVSpec	Precision Experiments in AMO Physics	3	WS/SS
MVSpec	Atomic and Molecular Spectroscopy	3	WS/SS
MVSpec	Atom Light Interactions	3	WS/SS
MVSpec	Theoretical Quantum Optics	3	WS/SS
MVSpec	Laser Physics	3	WS/SS
MVSpec	Atoms and Molecules in Strong Fields	3	WS/SS
MVSem	Advanced Seminar on Modern Topics in Atomic, Molecular and Optical Physics	6	WS/SS

Table 3.2.3 MSc Model study plan „Atomic, Molecular and Optical Physics”
[Beginning: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3) 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: 12 CP + 6 P = 18 CP			
	Experimental Optics and Photonics (4CP MVAMO1)	Advanced Quantum Theory (4 CP MVAMO2) Experimental Methods in Atomic, Molecular and optical Physics (4 CP MVAMO3)		
		Oral examination 6 CP		
Options		Condensed Matter Physics (8 CP MKEP2)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

Table 3.2.4 MSc Model study plan „Atomic, Molecular and Optical Physics”
[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules		Advanced Atomic, Molecular and Optical Physics (8 CP MKEP3) 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: 12 CP + 6 P = 18 CP			
	Advanced Quantum Theory (4 CP MVAMO2) Experimental Methods in Atomic, Molecular and optical Physics (4 CP MVAMO3)	Experimental Optics and Photonics (4CP MVAMO1)		
		Oral examination 6 CP		
Options	Condensed Matter Physics (8 CP MKEP2)			
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

<table>
<tr><td colspan="2">Code: MVAMO1</td><td colspan="3">Course Title: Experimental Optics and Photonics</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 4</td><td>Workload: 120 h</td><td>Teaching Hours: 3/week</td><td>Mode: WPM</td><td>Term: WS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Experimental Optics and Photonics” (2 hours/week)
• Exercise with homework (1 hours/week)

Module Contents:

• Ray optics
• Wave optics
• Beam optics, Gaussian optics
• Fourier optics
• Wave guides, fibre optics, integrated optics
• Interference and coherence
• Photons and atoms
• Amplification of light
• Laser theory
• Types of lasers
• Ultra-short laser pulses
• Non-linear optics
• Modern applications

Objective: Basic principles and experimental methods of optics and photonics.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of PEP1-PEP4

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: defined by lecturer before beginning of course</td></tr>
</table>

Code: MVAMO2		**Course Title**: Advanced Quantum Theory		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 4	**Workload:** 120 h	**Teaching Hours**: 3/week	**Mode**: WPM	**Term**: SS

Module Parts :

- Lecture on "Advanced Quantum Theory" (2 hours/week)
- Exercise (1 hours/week)

Module Contents (selection out of the following topics):

- Quantum theory of matter (Schrodinger 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)

Objective: Understanding of fundamental concepts of quantum physics and the relevant theoretical methods

Necessary/useful Knowledge: PEP1-PEP4

Recommended Literature: To be announced by lecturer

Specialties: –

Form of Testing and Examination: To be defined by lecturer before beginning of course

Code: MVAMO3		**Course Title**: Experimental Methods in Atomic, Molecular and Optical Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 4	**Workload:** 120 h	**Teaching Hours**: 3/week	**Mode**: WPM	**Term**: SS

Module Parts :

- Lecture on "Experimental Methods in Atomic, Molecular and Optical Physics" (2 hours/week)
- Exercise (1 hours/week)

Module Contents (selection out of the following topics):
- Quantum state preparation, trapping and cooling of neutral and charged particles
- Experiments with single photons
- Matter waves and atom interferometry
- Atomic and molecular Bose condensates and degenerate Fermi gases
- Quantum information with atoms, ions and molecules
- Precision measurements and metrology
- Atoms and molecules in ultra-short and ultra-strong laser fields

Objective: Modern aspects of experimental research in Atomic, Molecular and Optical Physics.

Necessary/useful Knowledge: PEP1 – PEP4

Recommended Literature: To be announced by lecturer

Specialties: –

Form of Testing and Examination: To be defined by lecturer before beginning of course

3.3 Biophysics

Table 3.3.1: Specialization Biophysics

Module code	Module	LP/CP	Term
MVBP1	Introduction to Biophysics	6	WS
MVBP2	Theoretical Biophysics	6	SS

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	WS/SS
MVSpec	Bio-photonics	2	SS
MVSpec	Astro biophysics III	2	WS
MVSpec	Scientific Visualization	2	WS/SS
MVSpec	Nonlinear Dynamics	2	WS/SS
MVSpec	Stochastic Dynamics	2	WS/SS
MVSpec	Radiation Biophysics	2	WS/SS
MVSem	Advanced Seminar on Biophysics	6	WS/SS
MVRS	Research Seminar on special topics of Biophysics	2	WS/SS
MVJC	Journal Club on Biophysics	2	WS/SS

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			
	Introduction to 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)	Introduction to 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**: Introduction to Biophysics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 6	**Workload**: 180 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on "Introduction to Biophysics" (4 hours/week)
- Exercise (2 hours/week)

Module 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

Objective: Introduction to basic concepts of biophysics; practical exercises.

Necessary/useful Knowledge: Content of PEP4, UKBio1, UKBio2

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVBP2		**Course Title**: Theoretical Biophysics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 6	**Workload:** 180 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: SS

Module Parts :
• Lecture on "Theoretical Biophysics" (4 hours/week)
• Exercise (2 hour/week)

Module 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

Objective: Introduction to theoretical concepts for physics of living matter

Necessary/useful Knowledge: Basics of Classical Mechanics, Electrodynamics and Statistical Mechanics
Recommended Literature: To be announced by lecturer
Specialties: Exercises with homework

Form of Testing and Examination: To be defined by lecturer before beginning of course

3.4 Condensed Matter Physics

Table 3.4.1: Specialization Condensed Matter Physics

Module code	Module	LP/CP	Term
MVCMP1	Low Temperature Physics	8	WS
MVCMP2	Surfaces and Nanostructures	6	WS
MVCMP3	Magnetism*	6	SS

*"Magnetism", depending on importance of actual research, topic may change to "Molecular Nanostructures", "Transition metal compounds" in the future

Table 3.4.2: Specialization Condensed Matter Physics (experimental condensed matter physics, organic electronics)
Specialised lectures and seminars
[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]

Code	Module	CP	Term
MVSpec	Semiconductor Physics I and II	4/4	WS/SS
MVSpec	Quantum Fluids	4	WS/SS
MVSpec	Low Temperature Detectors	4	WS/SS
MVSpec	Superconductors	4	WS/SS
MVSpec	Optical Properties of Condensed Matter	3	SS
MVSpec	Fundamentals of organic electronics	4	WS
MVSpec	Organic thin films	4	WS
MVSpec	Organic optoelectronics	4	SS
MVSpec	Printing technology for electronics	4	SS
MVSpec	Modelling of soft matter for organic semiconductors	2	SS
MVSem	Advanced Seminar on Condensed Matter Physics	6	SS
MVSem	Advanced Seminar on Organic Electronics	6	WS
MVLab	Laboratory Organic Electronics	2	SS
MVRS	Research Seminar on special topics of Condensed Matter Physics	2	WS/SS
MVJC	Journal Club on Condensed Matter Physics (including organic condensed matter)	2	WS/SS

Table 3.4.3 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 lecture 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 Magnetism (6 CP MVCMP3)		
		Oral examination 6 CP		
Options	Molecular and Optical Physics (8 CP MKEP3) or Condensed Matter Theory (8CP MVTheo2)	Journal Club on Condensed Matter 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

* If not already completed during the course of the Bachelor programme; otherwise Replaced with courses from the sector „Transferable Skills

Table 3.4.4 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			
	Magnetism (6 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 on Condensed Matter Physics (2 CP MVJC)	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

Table 3.4.5 MSc Model study plan „Condensed Matter Physics (Organic Electronics)
[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: 12 CP + 6 P = 18 CP			
	Fundamentals of organic electronics (4 CP MVSpec)	Organic optoelectronics, (4 CP MVSpec) Printing technology for electronics (4 CP MVSpec)		
		Oral examination 6 CP		
Options	Semiconductor Physics I (4 CP MVSpec) Organic thin films (4 CP MVSpec)[4)]	Semiconductor Physics II (4 CP MVSpec) Modelling of soft matter for organic semiconductors (2 CP MVSpec) Laboratory Organic Electronics (2 CP MVLab)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences			
Total CPs	min. 60 CP		30 CP	30 CP

* If not already completed during course of Bachelor programme; otherwise replaced with courses fromTransferable Skills

Table 3.4.6 MSc Model study plan „Condensed Matter Physics (Organic Electronics)"
[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			
	Organic optoelectronics, (4 CP MVSpec)[4)] Printing technologies for electronics (4 CP MVSpec)[4)] Modelling of soft matter for organic semiconductors (2 CP MVSpec)[4)]	Fundamentals of organic electronics (4 CP MVSpec) Oral examination 6 CP		
Options	Semiconductor Physics II (4 CP MVSpec)[)] Optical properties of Condensed Matter (3 CP, MVSpec) Laboratory Organic Electronics (2 CP MVLab)	Organic thin films (4 CP MVSpec)		
	Interdisciplinary courses, transferable skills, professional key competences and specific additional technical competences.			
Total CPs	min. 60 CP		30 CP	30 CP

4) If these lectures and lab courses are not offered, they can be replaced by MVCMP2, MVAMO1, MVBio2, UKEL2), respectively. 5) Or Semiconductor Physics I

Code: MVCMP1		**Course Title**: Low Temperature Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload**: 180 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on "Low Temperature Physics" (4 hours/week)
- Exercise (2 hour/week) and home works

Module Contents:

- Properties of quantum fluids: super fluid 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

Objective: Theoretical and experimental basics of condensed matter physics at low temperatures. Introduction to a modern field of research.

Necessary/useful Knowledge: Content of PEP4, PEP5

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

<table>
<tr><td colspan="2">Code: MVCMP2</td><td colspan="3">Course Title: Surfaces and Nanostructures</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises; visits to laboratory</td></tr>
<tr><td>Credit Points: 6</td><td>Workload: 180 h</td><td>Teaching Hours: 5/week</td><td>Mode: WPM</td><td>Term: WS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Surfaces and Nanostructures” (4 hours/week)
• Exercises with homework (1 hour/week)
• 2 Visits to Laboratory

Module Contents:

• Structure, electronic and vibration properties of surfaces
• Adsorbates, thin films, and nano-objects
• Dimension and size effects
• Experimental methods
• Formation of nanostructures (self-organization)

Objective: Theoretical and experimental basics on surfaces and nanostructures, familiarizing with the current research and its applications.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of PEP4, PEP5, PTP4

Recommended Literature: To be announced by lecturer

Specialties: The lecture course includes 2 visits to the laboratory and weekly homework.</td></tr>
<tr><td colspan="5">Form of Testing and Examination: defined by lecturer before beginning of course</td></tr>
</table>

<table>
<tr><td colspan="2">Code: MVCMP3</td><td colspan="3">Course Title: Magnetism</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 6</td><td>Workload: 180 h</td><td>Teaching Hours:
5/week</td><td>Mode:
WPM</td><td>Term:
WS</td></tr>
</table>

Module Parts:

- Lecture on “Magnetism” (4 hours/week)
- Exercises with homework (1 hour/week)

Module Contents:

- Basics, experimental methods
- Magnetism of atoms and ions
- Magnetism in solids: crystal fields, magnetism of free electrons
- Magnetic interactions
- Collective effects: spin ordering and phase transitions
- Interplay of spins, orbitals, electrons, and structure
- Colossal Magneto-resistance
- Quasi-1D magnetism
- Magnetism and high-temperature superconductivity

Objective: Theoretical and experimental basics on magnetism and magnetic materials, ranging from basics to current research. Emphasis on interplay of spins, orbitals, electrons, and structure in complex materials.

Necessary/useful Knowledge: Content of PTP4, MKEP2

Recommended Literature: To be announced by lecturer

Specialties:

Form of Testing and Examination: defined by lecturer before beginning of course

3.5 Environmental Physics

Table 3.5.1: Specialization Environmental Physics

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

Table 3.5.2: 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	WS/SS
MVSem	Advanced Seminar on Environmental Physics	6	WS/SS
MVRS	Research Seminar on special topics of Environmental Physics	2	WS/SS
MVJC	Journal Club on Environmental Physics	2	WS/SS

Table 3.5.3 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 3.5.4 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 (Master module)		**Course Title**: Atmospheric Physics		
Programme: Physics (Master)		**Type**: Lecture with exercises		
Credit Points: 4	**Workload**: 120 h	**Teaching Hours**: 3/week	**Mode**: WPM	**Term**: WS

Module Parts:

- Lecture on “Atmospheric Physics“ (2 hours/week)
- Exercise with homework (1 hour/week)

Module 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)

Objective: Advanced understanding of the physical and chemical processes of the Atmosphere in the Climate System

Necessary/useful Knowledge: Content of MKEP4

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: 1-hour written exam

<table>
<tr><td colspan="2">Code: MVEnv2 (Master module)</td><td colspan="3">Course Title: Physics of Terrestrial Systems</td></tr>
<tr><td colspan="2">Programme: Physics (Master)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 4</td><td>Workload: 120 h</td><td>Teaching Hours: 3/week</td><td>Mode: WPM</td><td>Term: WS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Soil Physics” (2 hours/week)
• Exercise with homework (1 hour/week)

Module Contents:

• Fluids in porous media
• Groundwater flow
• Soil water flow
• Solute transport

Objective: Advanced understanding of the physical processes of Terrestrial Systems in the Earth System</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of MKEP4

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 1-hour written exam</td></tr>
</table>

<table>
<tr><td colspan="2">Code: MVEnv3 (Master module)</td><td colspan="3">Course Title: Physics of Aquatic Systems</td></tr>
<tr><td colspan="2">Programme: Physics (Master)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 4</td><td>Workload: 120 h</td><td>Teaching Hours:
3/week</td><td>Mode:
WPM</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Physics of Aquatic Systems” (2 hours/week)
• Exercise with homework (1 hour/week)

Module 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

Objective: Advanced understanding of the physical processes in Aquatic Systems, the methods to study them, and their role in the Climate System</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of MKEP4

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 1-hour written exam</td></tr>
</table>

<table>
<tr><td colspan="2">Code: MVEnv4 (Master module)</td><td colspan="3">Course Title: Physics of Climate</td></tr>
<tr><td colspan="2">Programme: Physics (Master)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 4</td><td>Workload: 120 h</td><td>Teaching Hours: 3/week</td><td>Mode: WPM</td><td>Term: SS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Physics of the Climate System” (2 hours/week)
• Exercise with homework (1 hour/week)

Module 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

Objective: Advanced understanding of the Climate System and its major components and its past, present and future changes</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of MKEP4

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 90 minutes written exam</td></tr>
</table>

Code: MVEnv5		**Course Title:** Practical Environmental Physics		
Programme: Master of Science (Physics)		**Type:** Practical and laboratory course		
Credit Points: 1-7	**Workload**: 30-210 h	**Teaching Hours**: 3/topic	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Field- and laboratory studies on different topics of Environmental Physics (1LP/CP per topic; see below)

Module 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

Objective: Experimental skills for environmental field work and laboratory techniques

Necessary/useful Knowledge: Content of MKEP4

Recommended Literature: To be announced by lecturer

Specialities: Experimental laboratory and field work

Form of Testing and Examination: Oral examination

3.6 Medical Physics

Table 3.6.1: Specialization Medical Physics

Module code	Module	LP/CP	Term
MVMP1	Medical Physics 1	6	WS
MVMP2	Medical Physics 2	6	SS

Table 3.6.2: 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	WS
MVSpec	Advanced Biological Models in Radio Therapy	2	SS
MVSem	Advanced Seminar on Medical Physics	6	WS/SS
MVRS	Research Seminar on special topics of Medical Physics	2	WS/SS
MVJC	Journal Club on Medical Physics	2	WS/SS

Table 3.6.3 MSc Model study plan „Medical 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>Particle Physics
(8 CP MKEP1)
Advanced Atomic, Molecular and Optical Physics
(8 CP MKEP3)</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">Medical Physics I
(6 CP MVMP1)</td><td>Medical Physics II
(6 CP MVMP2)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Specialized lectures on Medical Physics
(2 CP MVSpec)</td><td>Specialized lectures on Medical Physics
(2 CP MVSpec)
Journal Club on Medical Physics
(2 CP MVSpec)</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>

* If not already completed during the course of the Bachelor programme; otherwise replaced with courses from the sector „Transferable Skills

Table 3.6.4 MSc Model study plan „Medical 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>Condensed matter physics
(8 CP MKEP2)
Environmental Physics
(8 CP MKEP4)</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 = 198CP</td></tr>
<tr><td rowspan="2">Medical Physics II
(6 CP MVMP2)</td><td>Medical Physics I
(6 CP MVMP1)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Specialized lectures on Medical Physics
(2 CP MVSpec)</td><td>Specialized lectures on Medical Physics
(2 CP MVSpec)
Journal Club on Medical Physics
(2 CP MVSpec)</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>

* If not already completed during the course of the Bachelor programme; otherwise replaced with courses from the sector „Transferable Skills

<table>
<tr><td colspan="2">Code: MVMP1</td><td colspan="3">Course Title: Medical Physics 1</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with Exercises</td></tr>
<tr><td>Credit Points: 6</td><td>Workload: 180 h</td><td>Teaching Hours:
6/week</td><td>Mode:
WPM</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts :

• Lecture on “Basics of x-ray imaging and radiation therapy” (4 hours/week)
• Exercise (2 hour/week)

Module 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

Objective: Detailed presentation of the underlying physics and basic biology for imaging with x-rays, radiotherapy with high energy photon beams, radiotherapy with hadron beams.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Basics on electromagnetic interactions and Fourier transformations

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: To be defined by lecturer before beginning of course</td></tr>
</table>

Code: MVMP2		**Course Title**: Medical Physics 2		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 6	**Workload:** 180 h	**Teaching Hours**: 6	**Mode**: WPM	**Term**: WS

Module Parts :

- Lecture on "Medical Physics 2" (4 hours/week)
- Exercise (2 hour/week)

Module 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

Objective: To provide a comprehensive introduction into morphological and physiological imaging and spin– and radioactive–tracer techniques.

Necessary/useful Knowledge: detector physics, rf-electronics, image processing, basics of biochemistry.

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: To be defined by lecturer before beginning of course

3.7 Particle Physics

Table 3.7.1: Specialization Particle Physics

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

Table 3.7.2: 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	WS/SS
MVSpec	New Physics Beyond the Standard Model	2	WS/SS
MVSpec	Statistical Methods in Particle Physics	4	WS/SS
MVSpec	Accelerator Physics	4	WS
MVSem	Advanced Seminar on Particle Physics	6	WS/SS
MVRS	Research Seminar on special topics of Particle Physics	2	WS/SS
MVJC	Journal Club on Particle Physics	2	WS/SS

Table 3.7.3 MSc Model study plan „Particle 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>Particle Physics
(8 CP MKEP1)
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: 16 CP + 6 P = 22 CP</td></tr>
<tr><td rowspan="2">Advanced Topics in Particle Physics
(4 CP MVHE1)</td><td>Physics of Particle Detectors
(4 CP MVHE2)
Standard Model in Particle Physics
(8 CP MVHE3)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Quantum Field Theory
(8 CP MVTheo1)</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>

* If not already completed during the course of the Bachelor programme; otherwise replaced with courses from the sector „Transferable Skills

Table 3.7.4 MSc Model study plan „Particle 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>Condensed Matter Physics
(8 CP MKEP2)</td><td>Quantum Field Theory
(8 CP MVTP)</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: 16 CP + 6 P = 22 CP</td></tr>
<tr><td rowspan="2">Particle Physics
(8 CP MKEP1)

Physics of Particle Detectors
(4 CP MVHE2)</td><td>Advanced Topics in Particle Physics
(4 CP MVHE1)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Specialized Lecture on Particle Physics
(2CP MVSpec)</td><td>Journal Club on Particle Physics 2 CP MVJC)</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: MVHE1		**Course Title**: Advanced Topics in Particle Physics		
Programme: Master of Science (Physics)		**Type**: Lecture and Journal Club		
Credit Points: 4	**Workload:** 120 h	**Teaching Hours**: 3/week	**Mode**: WPM	**Term**: WS/SS

Module Parts :
• 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)

Module 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

Objective: Overview of the experimental foundation of modern particle physics and introduction into today's main experimental questions. The tutorials provide the possibility for further discussions.

Necessary/useful Knowledge: Content of PEP5 (Bachelor), MKEP1 (Master)

Recommended Literature: To be announced by lecturer

Specialties: Journal Club to discuss actual research topics

Form of Testing and Examination: To be defined by lecturer before beginning of course

<table>
<tr><td colspan="2">Code: MVHE2</td><td colspan="3">Course Title: Physics of Particle Detectors</td></tr>
<tr><td colspan="2">Programme: Physics (Master)</td><td colspan="3">Type: Lecture, tutorial and exercises</td></tr>
<tr><td>Credit Points: 4</td><td>Workload: 120 h</td><td>Teaching Hours:
3/week</td><td>Mode:
WPM</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts:

• 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)

Module 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

Objective: Introduction of the detector techniques used in modern particle physics experiments. The tutorials, including exercises, provide the possibility for discussions.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of PEP4, PEP5, PTP4

Recommended Literature: announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: defined by lecturer before beginning of course</td></tr>
</table>

Code: MVHE3		**Course Title**: Standard Model of Particle Physics		
Programme: Master of Science (Physics)		**Type**: Lecture with Exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: SS

Module Parts :

• Lecture on “Standard Model of Particle Physics” (4 hours/week)
• Exercises with homework (2 hours/week)

Module Contents:

The focus of the lecture is the experimental tests of the building blocks of matter and The course will cover the Standard Model of Particle Physics from the theoretical and from the experimental perspective. The gauge theories of electroweak and strong interactions and their experimental tests will be described. The present status of the Standard Model, open experimental questions, and some directions of beyond the Standard Model physics are discussed. The course will include the necessary relativistic quantum field theory but with emphasis on applications rather than formal details.

Objective: Theoretical and experimental introduction into the Standard Model of Particle Physics. The lectures are therefore given by a theoretician and an experimentalist. Tutorials offer the possibility to discuss open questions and the exercises.

Necessary/useful Knowledge: Content of PEP5 (Bachelor) or MKEP1 (Master), PTP4 (Bachelor), MKTP1 (Master)

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: To be defined by lecturer before beginning of course

Code: MVPSI		**Course Title**: Advanced Particle Physics Project at the Paul Scherrer Institut		
Programme: Master of Science (Physics)		**Type**: Lecture and Laboratory Course		
Credit Points: 8	**Workload**: 240 h	**Teaching Hours**: 160 (total)	**Mode**: WPM	**Term**: WS/SS

Module Parts:

• Introduction to the experiment with Lectures (block course)
• Practical course (block course)

Module Content:

• Lectures about Particle Physics, detectors, electronics, computing and data analysis
• Planning and preparation of the experiment
• Construction and commissioning of the experiment
• Data taking 24 hours in shifts, calibrations and first data analysis
• Data Analysis and Final Results

Objective: The goal is to perform a complete particle physics experiment at a proton, pion or muon beamline. The course comprises the planning, construction and commissioning of the experiment as well as the operation and the data analysis. The students shall learn the basic experimental techniques in particle physics. Emphasis is put on the operation of the detectors, on the training in trigger electronics and data acquisition systems, and on the data analysis. The results of the experiment are documented in a final report.

Necessary/useful Knowledge: Content of PEP5, Introductory Lecture on Experimental Particle Physics and Physics of Particle Detectors (recommended).

Recommended Literature: To be announced by lecturer.

Specialties: Lectures and practical block course. Limited Number of Participants. Bachelor students may account for this module as “WPProj”.

Form of Testing and Examination: Written final report

3.8 Theoretical Physics

Table 3.8.1: Specialization Theoretical Physics

Module code	**Module**	**LP/CP**	**Term**
MVTheo1	Advanced Quantum Field Theory (QFT 2)	8	SS
MVTheo2	Condensed Matter Theory	8	WS

Table 3.8.2: 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	WS/SS
MVSpec	Supersymmetry and Supergravity	4-8	WS/SS
MVSpec	Gauge Theories, QCD	4-8	WS/SS
MVSpec	Physics Beyond the Standard Model	4-8	WS/SS
MVSpec	Special Topics in Field Theory	4	WS/SS
MVSem	Advanced Seminar on Theoretical Physics	6	WS/SS
MVRS	Research Seminar on special topics of Theoretical Physics	2	WS/SS
MVJC	Journal Club on Theoretical Physics	2	WS/SS

Table 3.8.3 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 3.8.4 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) 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 3.8.3 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 (8CPMVSpec)</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>

<table>
<tr><td colspan="2">Code: MVTheo1</td><td colspan="3">Course Title: Advanced Quantum Field Theory (QFT 2)</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Lecture with exercises</td></tr>
<tr><td>Credit Points: 8</td><td>Workload: 240 h</td><td>Teaching Hours:
6/week</td><td>Mode:
WPM</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts:

• Lecture on “Quantum Field Theory 2” (4 hours/week)
• Exercise with homework (2 hours/week)

Module 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

Objective: To have a clear understanding of the regularisation renormalisation programme in Φ4-theory and later of renormalisation in QED and non-abelian gauge theories (1-loop order). Finally the effective action and the modern renormalisation group approach should be discussed.</td></tr>
<tr><td colspan="5">Necessary/useful Knowledge: Content of PEP3, PTP4, MVTheo1, MKTP1

Recommended Literature: announced by lecturer

Specialties: Exercises with homework</td></tr>
<tr><td colspan="5">Form of Testing and Examination: defined by lecturer before beginning of course</td></tr>
</table>

Code: MVTheo2		**Course Title**: Condensed Matter Theory		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: SS

Module Parts:

- Lecture on Condensed Matter Theory (4 hours/week)
- Exercise (2 hour/week)

Module 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.

Objective: The goal is to give a comprehensible introduction into the topics and methods of modern condensed matter theory. The course consists of two parts. The first one starts with an instruction on the nowadays `traditional´ diagrammatic technique supplemented by a detailed survey of the problems which are solved using this method, including Landau's theory of quantum liquids and BCS theory of superconductivity. The second part of the course deals with problems which require the use of more advanced non-perturbative approaches such as renormalisation group transformations, bosonisation and Bethe Ansatz. These concepts will be introduced on the examples of quantum impurity problems such as potential scattering in Luttinger liquids, inter-edge tunnelling in fractional quantum Hall probes and Kondo effect in metals and mesoscopic quantum dots.

Necessary/useful Knowledge: Content of PTP4, MKTP1, Complex Analysis

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: To be defined by lecturer before beginning of course

3.9 Computational Physics

Table 3.9.1: Specialization Computational Physics

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

Table 3.9.2: 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	WS/SS
MVSpec	Advanced Parallel Computing	4-6	WS/SS
MVSpec	Computational Fluid Dynamics	4-6	WS/SS
MVSpec	Computational Imaging	4-6	WS/SS
MVSpec	Computational Optics	4-6	WS/SS
MVSpec	GPU programming	4	WS/SS
MVSpec	Image Analysis	8	WS/SS
MVSpec	Introduction to High-Performance Computing	4-6	WS/SS
MVSpec	Inverse Problems	8	WS/SS
MVSpec	Machine Learning	8	WS/SS
MVSpec	Radiative Transfer	4	WS/SS
MVSpec	Scientific Programming	4-6	WS/SS
MVSpec	Volume Visualization	8	WS/SS
MVSem	Computer Vision	6	WS/SS

Table 3.9.3 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)	Core course from area of specialization MK+++	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 3.9.4 MSc Model study plan „Computational Physics“
[Beginning: summer semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core courses & research modules	Core course from area of specialization MK+++	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**: Fundamentals of Simulation Methods		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 8	**Workload:** 240 h	**Teaching Hours**: 6/week	**Mode**: WPM	**Term**: WS

Module Parts:

• Lecture on "Fundamentals of Simulation Methods" (4 hours/week)
• Exercise with homework (2 hours/week)

Module 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

Objective:

Endow students with the capacity to identify and classify numerical problems; reach active understanding of applicable numerical methods and algorithms; solve basic physical problems with adequate numerical techniques; recognize range of validity of numerical solutions.

Necessary/useful Knowledge: Not required but useful is prior knowledge in a programming language and experience with plotting software.

Recommended Literature: Will be announced by lecturer

Specialties: Exercises with homework

Form of Testing and Examination: defined by lecturer before beginning of course

Code: MVComp2		**Course Title**: Computational Statistics and Data Analysis		
Programme: Master of Science (Physics)		**Type**: Lecture with exercises		
Credit Points: 6	**Workload:** 180 h	**Teaching Hours**: 4/week	**Mode**: WPM	**Term**: SS

Module Parts:

• Lecture on Computational Statistics and Data Analysis (2 hours/week)
• Exercise (2 hour/week) with computational homework

Module 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

Objective:

Students should understand fundamental concepts of stochastics, and be able to relate them to concrete problems. Students should understand and be alert to pitfalls such as overfitting, multiple comparisons, or susceptibility to outliers. They should understand and be able to apply basic countermeasures; and should gain access to more advanced literature on the subject. Students should gain familiarity with relevant high-level languages and statistical programming libraries, and learn to apply them to real-world data provided in the exercises.

Necessary/useful Knowledge: Linear Algebra

Recommended Literature: To be announced by lecturer

Specialties: Exercises with computational homework

Form of Testing and Examination: To be defined by lecturer before beginning of course

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 which are also offered to Bachelor students 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	SS/WS
UKPVD	Course on teaching and learning (didactics)	1	SS/WS
UKPVP	Course on teaching and learning (practical)	2	SS/WS

Table 4.2: Professional key competences

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

Table 4.3: Specific additional technical competences

Module code	Module	LP/CP	Term
General technical competences			
UKNum	Practical Course: Numerical Methods	3	WS
UKSta	Practical Course: Statistical Methods	3	SS
Additional technical competences in mathematics			
UKMath1	Higher course in analysis	8	WS
UKMath2	Introduction to numerical calculations	8	SS
UKMath3	Partial differential equations	8	
Additional competences in scientific computation			
UKWR1	Scientific computation 1	8	WS
UKWR2	Introduction to computer physics	6	SS
Additional competences in electronics			
UKEL1	Electronics and electronic laboratory course	7	WS
UKEL2	Microelectronics and electronic laboratory course	7	WS
Additional competences in computer science			
UKInf1 (IPR*)	Introduction to applied computation	7	WS
UKInf2	Introduction to technical computation	7	SS
UKInf3	Computer science laboratory	6	WS/SS
UKInf4 (IAD)*	Algorithms and data structures	7	SS
UKInf5 (IBN)*	Operating systems and networks	7	WS
UKInf6 (IDB)*	Introduction to databases	4	SS
UKInf7 (ISE)*	Introduction to software engineering	4	WS
UKInf8 (ITH)*	Introduction to theoretical computer science	7	SS
Additional competences in chemistry			
UKChe	General chemistry	12	SS/WS
Additional competences in biology			
UKBio	Fundamentals of cellular and molecular biology	8	WS
Additional competences in economics			
UKPö1a	Introduction to political economics	8	WS
UKPö1b	Corporate Governance	8	WS
UKPö2a	Macro economics	8	SS
Additional competences in physiology			
UKPhy 1	Introduction to physiology and medical biophysics	4	SS
UKPhy 2	Cellular and molecular foundations of medical biophysics	4	WS

Table 4.4: Modules in Computer Science

Module code	**Module**	**LP/CP**	**Term**
MWInf1	Parallel Computer Architectures	8	SS
MWInf2	Digital Circuit Technology	8	WS
MWInf3	Design of VLSI Circuits using VHDL	4	SS
MWInf4	Embedded Systems	4	WS
MWInf5	Physics of Imaging	4	WS
MWInf6	Image Processing	7	WS
MWInf7	Pattern Recognition	7	WS

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	WS/SS
MFP	Methods and Project Planning	15	WS/SS
MFA	Master Thesis	30	WS/SS

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.

<table>
<tr><td colspan="2">Code: MFS</td><td colspan="3">Course Title: Scientific Specialization</td></tr>
<tr><td colspan="2">Programme: Master of Science (Physics)</td><td colspan="3">Type: Practice Course</td></tr>
<tr><td>Credit Points: 15</td><td>Workload: 450 h</td><td>Teaching Hours: –</td><td>Mode: PM</td><td>Term: WS/SS</td></tr>
<tr><td colspan="5">Module Parts:

• Preparation Course Master Thesis

Module Contents:

•To pass this module the student has to be part of a research group.
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.

Objective: Obtaining advanced knowledge in the research field of the planned master thesis.</td></tr>
<tr><td colspan="5">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.

Necessary/useful Knowledge: Advanced knowledge in research area in which master thesis is planned.

Recommended Literature: Given by supervisor.

Specialties: Work within a research group under supervision of the group leader.</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Oral report on the content of the module.</td></tr>
</table>

Code: MFP		**Course Title**: Methods and Project Planning		
Programme: Master of Science (Physics)		**Type**: Practice Course		
Credit Points: 15	**Workload:** 450 h	**Teaching Hours**: –	**Mode**: PM	**Term**: WS/SS

Module Parts:

• Preparation Course Master Thesis

Module Contents:

•To pass this module the student has to be part of a research group.
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.

Objective: Obtaining advanced knowledge in the research field of the planned master thesis.

Prerequisites: MFS

Necessary/useful Knowledge: Advanced knowledge in research area in which master thesis is planned.

Recommended Literature: Given by supervisor.

Specialties: Work within a research group under supervision of the group leader.

Form of Testing and Examination: Oral report on the content of the module.

Code: MFA		**Course Title**: Master Thesis		
Programme: Master of Science (Physics)		**Type**: Practice Course		
Credit Points: 30	**Workload:** 900 h	**Teaching Hours**: None	**Mode**: PM	**Term**: WS/SS

Module Parts:

- Master Thesis

Module Contents:

- Research work on a specific physics topic.

Objective: Supervised research work in a specific research area of physics.

Prerequisites: MFS and MFP

Necessary/useful Knowledge: Advanced knowledge on the research area of the master thesis.

Recommended Literature: Given by supervisor.

Specialties: Work within a research group under supervision of the group leader.

Form of Testing and Examination: Written master thesis.

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 3.8.

Table 5.1 MSc Model study plan „Experimental 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>Particle Physics
(8 CP MKEP1)</td><td>Condensed Matter Physics
(8 CP MKEP2)</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: 14 CP + 6 P = 20 CP</td></tr>
<tr><td rowspan="2">Advanced Lecture on Special Topics
(6CP MVSpec)</td><td>Advanced Atomic, Molecular and Optical Physics
(8 CP MKEP3)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td>Theoretical Statistical Physics
(8 CP MKTP1)</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>

Table 5.2 MSc Model study plan „Experimental 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>Condensed Matter Physics
(8 CP MKEP2)</td><td>Particle Physics
(8 CP MKEP1)</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: 14 CP + 6 P = 20 CP</td></tr>
<tr><td rowspan="2">Advanced Atomic, Molecular and Optical Physics
(8 CP MKEP3)</td><td>Advanced Lecture on Special Topics
(6 CP MVSpec)</td></tr>
<tr><td>Oral examination 6 CP</td></tr>
<tr><td rowspan="2">Options</td><td></td><td>Theoretical Statistical Physics
(8 CP MKTP1)</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>