

Master of Science in Physics (MSc Physik)

**Information on core and specialised
course modules**

1. The master degree in physics	3
2. Core and mandatory courses of the Master degree programme	5
3. Specialisation courses in physics (mandatory).....	18
3.1. Astronomy and Astrophysics	22
3.2. Atomic, Molecular and Optical Physics	30
3.3. Biophysics	35
3.4. Condensed Matter Physics	39
3.5. Environmental Physics	42
3.6. Medical Physics.....	48
3.7. Particle Physics	51
3.8. Theoretical Physics	55
4. Options	60
5. Model study plans	70

The master degree in physics

The research oriented master's programme in physics builds on the bachelor's 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's study, also obtain a deeper insight into other neighbouring fields of physics, depending on the choice of modules taken. In addition, the master's 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 specialisation either in a chosen, specific area of physics, or within an interdisciplinary area of research. The master's 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's students to follow their own specific interests.

The first two semesters (first year) of the master's 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's 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, specialisation and elective courses on offer for the master's 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 14 CP must be gained through successfully completing specialisation courses, and up to 24 CP must be gained through the successful completion of optional courses, 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. A further 6 CP are to be gained from successfully completing the final oral examination itself. In the second year or research phase of the master's degree, the course points are made up of two mandatory modules, „Scientific Specialisation“ and „Methods and Project Planning“, each being assigned 15 CP, as well as the master's thesis itself, which counts 30 CP. Thus, in total, a master's student is required to obtain 120 credit points during the course of the two years. Further details are laid down by the Rules and Regulations for master students.

In Table I, an overview is given of the master's programme and the credit points assigned to each course sector. The actual modules for different fields of specialisation are summarized in the chapters following this. Note that within the core, specialisation and elective 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.

Tabel 1: Overview of the Master degree programme

Modules	Code	CP
Core courses (Mandatory)		
Two of the following courses must be successfully completed:		
(1) Theoretical Statistical Physics	MKTP1	8
(2) Theoretical Astrophysics	MKTP2	8
(3) Particle Physics	MKEP1	8
(4) Condensed Matter Physics	MKEP2	8
(5) Advanced Atomic, Molecular and Optical Physics	MKEP3	8
(6) Environmental Physics	MKEP4	8
(7) Observational Astronomy	MKEP5	8
Total number of credit points – core courses		16
Specialisation courses in physics (mandatory)		
Advanced seminar in field of speciality	MVSem	2
Further speciality courses in physics	Appendix 2	12
Total number of credit points – speciality courses in physics		14
Options		
Courses within physics, or in neighbouring or interdisciplinary fields	Appendix 3	24
Total number of credit points – options		24
Oral examination (mandatory)		
Final oral examination on the two core courses as well as the speciality courses studied	MPr	6
Total number of credit points – oral examination	MPr	6
Research phase		
Mandatory module „Field of Specialisation“	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 in Physics		120

2. Core and other mandatory courses

The master's degree is made up of: (1) course work (consisting of core modules, modules of specialised fields and elective modules) (2) the oral examination plus (3) the one year research phase made up of the modules MFS, MFP und MFA.

The core modules: Two such modules yielding a total of 16 CP must be chosen from the list of core courses that is given in Table 2 and be successfully completed by the student. If the modules listed here have already been successfully completed by the student during the course of the bachelor's programme, the student may be exempted from repeating these courses; however, in such cases, master's students are required to choose alternative courses from the core and/or specialisation courses on offer, in order to acquire the full number of credit points needed in this sector. 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's Degree in Physics and Astronomy.)

Possible topics for the mandatory seminars, as well as the specialisation courses and journal clubs are listed in the paragraph „Specialisation Courses in Physics and Astronomy“.

In Table 3, the modules for the oral examination and research phase are listed.

Table 2: Core courses (mandatory)

Modulecode	Module	LP/CP	Term
MKTP1	Theoretical Statistical Physics	8	WS
MKTP2	Theoretical Astrophysics	8	WS
MKEP1	Particle Physics	8	WS
MKEP2	Condensed Matter Physics	8	SS
MKEP3	Advanced Atomic, Molecular and Optical Physics	8	WS
MKEP4	Environmental Physics	8	WS/SS
MKEP5	Observational Astronomy	8	SS

Table 3: Final oral examination and the research phase

Modulecode	Module	LP/CP	Term
MPr	Oral Examination	6	WS/SS
MFS	Scientific Specialisation	15	WS/SS
MFP	Methods and Project Planning	15	WS/SS
MFA	Master Thesis	30	WS/SS

Code: MKTP1		Course Title: Theoretical Statistical Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 3/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Statistical Physics” (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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. <p>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.</p>				
Necessary/useful Knowledge: Content of PEP3, PTP4				
Recommended Literature: announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MKTP2		Course Title: Theoretical Astrophysics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on Theoretical Astrophysics (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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 • Plasmaphysics (6): Basics of collisionless 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 <p>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</p>				
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: defined by lecturer before beginning of course				

Code: MKEP1		Course Title: Particle Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Introductory Lecture on Experimental Particle Physics (4 hours/week) • Exercises with homework (2 hours/week) Module Contents: <p>The focus of the lecture are the experimental tests of the building blocks of matter and their fundamental interactions:</p> <ul style="list-style-type: none"> • 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 <p>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.</p>				
Necessary/useful Knowledge: Content of PEP4, PEP5, PTP4 Literature: announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MKEP2		Course Title: Condensed Matter Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises, seminar		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on Condensed Matter Physics (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • Formation and structure of solids • Defects • Crystal binding • Structure determination • Lattice dynamics in the harmonic approximation • Non-harmonic properties of the atomic lattice • Electrons in the solid's potential • Transport of electrons in the solid • Dielectric and optical properties • Semiconductor Physics • Magnetism • Superconductivity Objective: Introduction to current questions in condensed matter physics.				
Necessary/useful Knowledge: Content of PEP1-PEP4				
Recommended Literature: To be announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: 2-hour written exam				

Code: MKEP3		Course Title: Advanced Atomic, Molecular and Optical Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on Advanced Atomic, Molecular and Optical Physics (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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 radiationless 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: defined by lecturer before beginning of course				

Code: MKEP4		Course Title: Environmental Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: WS/SS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on “Environmental Physics” (4 hours/week) • Exercise with homework (2 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • 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 <p>Objective: Fundamental understanding of the physical processes and interactions of the Earth system</p>				
Necessary/useful Knowledge: Content of PEP1-PEP3				
Recommended Literature: To be announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: 2-hour written exam				

Code: MKEP5		Course Title: Observational Astronomy		
Program: Master of Science (Physics)		Type: Lecture with exercises, laboratory course		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on “Observational Astronomy” (4 hours/week) • Exercises with homework (2 hour/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Optical telescopes (2): optics, refractors, reflectors, aberrations and corrections, refraction and diffraction, interference, resolution, focal ratio and aperture, different mirror types and foci, mountings, applications. • Optical detectors (4): Quantum / thermal / (in-) coherent detectors, photometers, photomultipliers, photographic plates, semiconductors, CCDs. Photoelectric effect, quantum efficiency, noise sources, camera types, surveys and techniques. • Imaging techniques (5): imaging, coronagraphy, drift scans, time-delay integration, orthogonal transfer CCDs, atmospheric effects and corrections, active and adaptive optics, Strehl, isoplanatic angle, wavefront sensing, MCAO and laser guide stars, turbulence, coherence length, satellites, applications. • Spectroscopy (3): types of spectrographs, prisms, gratings, grisms, slits, fibers, Echelle, cross dispersers, integral field units, Fabry-Perot, applications. • Infrared detectors (3): cryostats, chopping, photoconductors, photodiodes, bolometers, arrays, satellites, circular variable filters, applications. • Radio astronomy (3): Rayleigh-Jeans, brightness temperature, types and sources of thermal and non-thermal radiation, reflector types, foci, mountings, antenna types, receivers, single dish and synthesis techniques, applications. • X-ray and gamma astronomy (3): sources, synchrotron radiation, Bremsstrahlung, inverse Compton effect, matter-antimatter annihilation, nuclear reactions, atomic transitions; collimation, Wolter telescope, coded mask imaging, proportional counters, micro-channel plates, calorimeters, scintillators, solid state detectors, Compton scattering, pair production, Cherenkov radiation, applications. • Astroparticle physics (3): Sources of neutrinos and cosmic rays, acceleration mechanisms, neutrino and Cherenkov detectors, solar neutrino prob., applications. • Gravity waves (1): Hulse-Taylor, laser interferometry, sources, applications. • In-situ exploration and remote sensing (3): passive/active, cratering, meteorites, comets, planetary missions, instruments and spacecrafts, measurement techniques for composition and gravity, detectors, applications. <p>Objective: Construction of modern astronomical telescopes and instruments, their physics and their functional properties for students with special interest in astronomy.</p>				

Necessary/useful Knowledge: Basic knowledge on electromagnetic radiation; introduction to Astronomy and Astrophysics (WPAstro or MVAstro0)

Recommended Literature: To be announced by lecturer

Specialities: Exercises with homework

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

Code: MPr		Course Title: Oral Master Examination		
Program: Master of Science (Physics)		Type: Oral Exam		
Credit Points: 6	Workload: 180 h	Teaching Hours: –	Mode: PM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> Oral Examination on experimental and theoretical physics Module Contents: <ul style="list-style-type: none"> Oral examination on (1) the content of two lectures of the core course program (“Kursprogramm”, i.e. MKTP1, MKTP2, MKEP1, MKEP2, MKEP3, MKEP4 and MKEP5) and (2) the content of selected specialized physics courses corresponding to 14 credit points in total (“Specialisation Physik”). Objective: Proof of a thorough understanding on different physics research fields and their interconnections.				
Prerequisites: 46 Credit Points (LP/CP), of which 20 Credit Points are from lectures of the core course program (“Kursprogramm”) and the specialisation area (“Specialisation”). Necessary/useful Knowledge: Knowledge on the physics topics chosen for the exam. Recommended Literature: – Specialties: –				
Form of Testing and Examination: Oral examination				

Code: MFS		Course Title: Scientific Specialisation		
Program: Master of Science (Physics)		Type: Practice Course		
Credit Points: 15	Workload: 450 h	Teaching Hours: –	Mode: PM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> • Preparation Course Master Thesis Module Contents: <ul style="list-style-type: none"> • 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 to 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: MPr 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: MFP		Course Title: Methods and Project Planning		
Program: Master of Science (Physics)		Type: Practice Course		
Credit Points: 15	Workload: 450 h	Teaching Hours: –	Mode: PM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> • Preparation Course Master Thesis Module Contents: <ul style="list-style-type: none"> • For 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 to 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: Introduction to scientific and technical methods needed for the master thesis; self-planning of the thesis work.				
Prerequisites: MPr 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		
Program: Master of Science (Physics)		Type: Practice Course		
Credit Points: 30	Workload: 900 h	Teaching Hours: None	Mode: PM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> • Master Thesis Module Contents: <ul style="list-style-type: none"> • Research work on a specific physics topic. Objective: Supervised research work in a specific research area of physics.				
Prerequisites: MPr 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 and oral presentation.				

2. Specialisation courses in physics (mandatory)

For the specialization component of the master's degree in physics, students are required to select modules in one or two different fields of physics. These may be chosen from the courses listed in this chapter, but may also be selected from the list of core courses given in Chapter 2. For this component of the master's degree, a total of 14 CP is required.

Note that the modules listed here can also be selected as courses for the sector „Options“.

While master's 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 that are given in Chapter 5, which 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 the tables 5,7,9,11,13,15,17 and 19. Note, however, that not all modules will be offered on a regular basis. In particular, the specialisation 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 4 and are assigned unspecific, generic module codes, MVSpec, MVSem 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 specialisation 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 specialisation courses (MVSpec) can be seen in Tables 6,8,10,12,14,16,18 and 20.

Table 4: Specialisation courses, seminars und journal clubs

Modulecode	Module	LP/CP	Term
MVSpec	Advanced Lecture on Special Topics	2-8	WS/SS
MVSem	Advanced Seminar	2	WS/SS
MVJC	Journal Club	2	WS/SS

Code: MVSpec		Course Title: Advanced Lecture on Special Topic		
Program: 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: <ul style="list-style-type: none"> • Advanced Lecture on Special Topic Module Contents: <ul style="list-style-type: none"> • 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: MVSem		Course Title: Advanced Seminar		
Program: Master of Science (Physics)		Type: Seminar		
Credit Points: 2	Workload: 60 h	Teaching Hours: 2/week	Mode: WPM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> Advanced Seminar Module Contents: <ul style="list-style-type: none"> 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		
Program: Master of Science (Physics)		Type: Seminar		
Credit Points: 2	Workload: 60 h	Teaching Hours: 2/week	Mode: WPM	Term: WS/SS
Module Parts: <ul style="list-style-type: none"> Journal Club Module Contents: <ul style="list-style-type: none"> 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.				

3.1 Astronomy and Astrophysics

Table 5: Specialisation Astronomy and Astrophysics

Modulecode	Module	LP/CP	Term
MVAstro0	Introduction to Astronomy	7	WS
MVAstro1	Observational Methods	6	WS
MVAstro2	Stellar Astronomy and Astrophysics	6	SS
MVAstro3	Galactic and Extragalactic Astrophysics	6	WS
MVAstro4	Cosmology	6	SS

Table 6: Specialised lectures and seminars

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

Modulecode	Module	LP/CP	Term
MVSpec	Laboratory Course Astrophysics I	3	WS/SS
MVSpec	Laboratory Course Astrophysics II	3	WS/SS
MVSpec	Observing the Big Bang	3	WS
MVSem	Advanced Seminar on Astronomy or Astrophysics	2	WS/SS
MVJC	Journal Club on Astronomy or Astrophysics	2	WS/SS

Code: MVAstro0		Course Title: Introduction to Astronomy		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 7	Workload: 210 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
<p>Module Parts:</p> <ul style="list-style-type: none"> Lecture on Introduction to Astronomy and Astrophysics with Exercises (6 hours/week: 3 weeks block course in Sept.) <p>Module Contents:</p> <p>Lecture „Introduction to Astronomy and Astrophysics“</p> <ul style="list-style-type: none"> 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 tunneling; 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 re-ionization Cosmological boundary conditions (3): Friedmann-Lemaître models, cosmological standard model; origin and evolution of structures; halos of Dark Matter; Formation of galaxies <p>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.</p>				

Necessary/useful Knowledge: Basic knowledge on electromagnetic radiation and Fourier theory

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework

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

Code: MVAstro1		Course Title: Observational Methods		
Program: Master of Science (Physics)		Type: Lecture and laboratory course		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on Observational Methods (4 hours/week) • Laboratory Course (2 hours/week) <p>Module Contents:</p> <p>Module Part 1: Lecture „Observational Methods“ (4 LP)</p> <ul style="list-style-type: none"> • 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 <p>Module Part 2: Astrophysical Laboratory Course II (2 LP)</p> <p>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:</p> <ul style="list-style-type: none"> • 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 <p>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.</p>				

Necessary/useful Knowledge: Basic knowledge on electromagnetic radiation and Fourier theory; content of “Introduction to Astronomy and Astrophysics I and II” (WPAstro); content of MKTP2

Recommended Literature: To be announced by lecturer

Specialties: Exercises with homework and laboratory course

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

Code: MVAstro2		Course Title: Stellar Astronomy and Astrophysics		
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: <ul style="list-style-type: none"> • 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) <ul style="list-style-type: none"> • 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) <ul style="list-style-type: none"> • 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 Astrophysics		
Program: 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: <ul style="list-style-type: none"> • Lecture on “Galactic and Extragalactic Astrophysics” (2 hours/week) • Exercise (1 hour/week) • Seminar on Special Topic in “Galactic and Extragalactic Astrophysics” (2 hours/week) Module Contents: Module Part 1: Lecture “Galactic and Extragalactic Astrophysics” (4 LP) <ul style="list-style-type: none"> • Galaxy formation and evolution (3): cosmological initial conditions, semi-analytic models; angular momentum, discs and star formations; population synthesis and chemical evolution; merging; structure and dynamics of the Milky Way; • Active galaxies (4): Black Holes in galaxies; continuum and line spectra, variability; emission mechanisms and unified models; cosmological evolution; feedback of active galaxies on the environment; • Galaxy clusters (4): Optical, X—ray and radio emission, Sunyaev-Zel'dovich effect; models, scaling relations and deviations; galaxy populations; cosmological evolution; • Large scale matter distribution (2): Correlation functions; biasing mechanisms; deformations in redshift space, velocity field; statistics and cosmological evolution of intergalactic absorption lines; • Cosmic radiation (2): Properties and interpretation of the X-ray and infrared background; Cosmic Rays, acceleration mechanisms and transport effects; cosmic re-ionization, physical mechanisms and observations Module Part 2: Seminar (2LP) <ul style="list-style-type: none"> • Presentations and discussions on actual topics in galactic and extragalactic astrophysics Objective: Detailed presentation of the physics of normal and active galaxies, galaxy clusters and larger structures as well as the cosmological evolution 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: MVAstro4		Course Title: Cosmology		
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: <ul style="list-style-type: none"> • 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) <ul style="list-style-type: none"> • Homogeneous and isotropic cosmology (4): Friedmann-Lemaître models, geometry, redshift and dynamics; parameters, distance measures and ages; thermal evolution, freezing out of reactions; primordial nucleosynthesis 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 ModulePart 2: Seminar (2LP) <ul style="list-style-type: none"> • 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 7: Specialisation Atomic, Molecular and Optical Physics

Modulecode	Module	LP/CP	Term
MVAMO1	Experimental Optics and Photonics	4	SS
MVAMO2	Theoretical Quantum Optics and Photonics	4	WS
MVAMO3	Ultracold Quantum Matter and Quantum Engineering	4	SS
MVAMO4	Stored Particles	4	WS

Table 8: Specialised lectures and seminars

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

Modulecode	Module	LP/CP	Term
MVSpec	Strong Laser Fields	4	SS
MVSpec	Advanced Quantum Chemistry	4	WS
MVSpec	Advanced Quantum Theory	3	SS
MVSpec	Special Topics in Experimental AMO Physics	3	WS/SS
MVSem	Advanced Seminar on AMO Physics	2	WS/SS
MVJC	Journal Club on AMO Physics	2	WS/SS

Code: MVAMO1		Course Title: Experimental Optics and Photonics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Experimental Optics and Photonics” (2 hours/week) • Exercise with homework (1 hours/week) Module Contents: <ul style="list-style-type: none"> • Ray optics • Wave optics • Beam optics, Gaussian optics • Fourier optics • Wave guides, fibre optics, integrated optics • Interference, coherence • Photons and atoms • Amplification of light • Laser theory • Types of lasers • Pulsed lasers • Non-linear optics • Modern applications Objective: Basic principles and experimental methods of optics and photonics.				
Necessary/useful Knowledge: Content of PEP1-PEP3 Recommended Literature: To be announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MVAMO2		Course Title: Theoretical Quantum Optics and Photonics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: WS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Theoretical Quantum Optics and Photonics” (2 hours/week) • Exercise (1 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Quantum states and light • Semi-classical theory of atom-field interaction • Quantum coherence and interference • Basics of quantum information theory • Sources and mechanisms of decoherence • Multi-photon and relativistic quantum optics <p>Objective: Basic theoretical knowledge on Quantum Optics and Photonics</p>				
<p>Necessary/useful Knowledge: –</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: –</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

Code: MVAMO3		Course Title: Ultra cold Quantum Matter and Quantum Engineering		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Ultra cold Quantum Matter and Quantum Engineering” (2 hours/week) • Exercise (1 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Review of cooling techniques • Basic properties of ultra cold Bose gases and liquids • Discussion of fundamental experiments with bosonic gases/liquids • Introduction to the physics of ultra cold Fermi gases • Discussion of fundamental experiments with fermionic gases • Review of ion traps and ion cooling • Quantum information experiments in atomic and molecular physics <p>Objective: Modern aspects of experimental research in field of Ultra cold Quantum Matter and Quantum Engineering.</p>				
<p>Necessary/useful Knowledge: –</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: –</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

Code: MVAMO4		Course Title: Stored Particles		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Stored Particles” (2 hours/week) • Exercise (1 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Storage and cooling of charged particles • Storage and cooling of neutral particles • Measurements of ground state properties • Radiative and collision processes of stored particles • Fundamental physical constants • Fundamental symmetries and interactions • Future perspectives <p>Objective: Modern aspects of experimental research in the field of Stored Particles.</p>				
<p>Necessary/useful Knowledge: –</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: –</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

3.3 Biophysics

Table 9: Specialisation Biophysics

Modulecode	Module	LP/CP	Term
MVBio1	Introduction to Biophysics	6	SS
MVBio2	Theoretical Biophysics	6	WS

Table 10: Specialised lectures and seminars

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

Modulecode	Module	LP/CP	Term
MVSpec	Fundamental of Optics in Biophysics	4	WS/SS
MVSpec	Medical Image Processing	4	WS/SS
MVSpec	Scientific Visualization	4	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	2	WS/SS
MVJC	Journal Club on Biophysics	2	WS/SS

Code: MVBio1		Course Title: Introduction to Biophysics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Introduction to Biophysics” (4 hours/week) • Exercise (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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, UKBio Recommended Literature: To be announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MVBio2		Course Title: Theoretical Biophysics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Theoretical Biophysics” (4 hours/week) • Exercise (2 hour/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Macromolecules <ul style="list-style-type: none"> - 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 behavior of folded macromolecules - Genes: Gene expression and genetic code • Membranes <ul style="list-style-type: none"> - Self-assembly of micelles - Surface behavior of lipids: differential geometry of surfaces, membrane elasticity and bending energy, membrane fluctuations - Structure of Lipids - Cell Membranes • Transport <ul style="list-style-type: none"> - Diffusion - Polymer dynamics: Rouse Model, hydrodynamic interactions, reptation • Networks <ul style="list-style-type: none"> - Gels - Metabolic Networks: Boolean networks, scale-free networks, robustness of networks • Molecular Motors <ul style="list-style-type: none"> - Polymerization of cell filaments - Brownian ratchet - A basic model of a molecular motor • Statistical Analysis <ul style="list-style-type: none"> - Bayesian Analysis - Monte Carlo Methods - Hidden Markov Models <p>Objective: Introduction to theoretical concepts for physics of living matter</p>				

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 11: Specialisation Condensed Matter Physics

Modulecode	Module	LP/CP	Term
MVCMP1	Low Temperature Physics	6	WS
MVCMP2	Surfaces and Nanostructures	6	WS

**Table 12: Specialisation Condensed Matter Physics;
Specialised lectures and seminars**

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

Modulecode	Module	LP/CP	Term
MVSpec	Semiconductor Physics	6	WS/SS
MVSpec	Modern Solid State Physics	6	WS/SS
MVSpec	Quantum Fluids	4	WS/SS
MVSpec	Low Temperature Detectors	4	WS/SS
MVSpec	Superconductors	4	WS/SS
MVSem	Advanced Seminar on Condensed Matter Physics	2	WS/SS
MVJC	Journal Club on Condensed Matter Physics	2	WS/SS

Code: MVCMP1		Course Title: Low Temperature Physics		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Low Temperature Physics” (4 hours/week) • Exercise (2 hour/week) Module Contents: <ul style="list-style-type: none"> • Properties of quantum fluids: superfluid ^3He and ^4He, normalfluid ^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				

Code: MVCMP2		Course Title: Surfaces and Nanostructures		
Program: Master of Science (Physics)		Type: Lecture with exercises; visits to laboratory		
Credit Points: 6	Workload: 180 h	Teaching Hours: 5/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Surfaces and Nanostructures” (4 hours/week) • Exercises with homework (1 hour/week) • 2 Visits to Laboratory Module Contents: <ul style="list-style-type: none"> • 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.				
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.				
Form of Testing and Examination: defined by lecturer before beginning of course				

3.5 Environmental Physics

Table 13: Specialisation Environmental Physics

Modulecode	Module	LP/CP	Term
MVEnv1	Atmospheric Physics	3	WS
MVEnv2	Physics of Terrestrial Systems	3	WS
MVEnv3	Physics of Aquatic Systems	3	SS
MVEnv4	Physics of Climate	3	SS
MVEnv5	Practical Environmental Physics	1-7	SS

**Table 14: Specialisation Environmental Physics;
Specialised lectures and seminars**

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

Modulecode	Module	LP/CP	Term
MVSpec	Special Topics Environmental Physics	2	WS/SS
MVSem	Advanced Seminar on Environmental Physics	2	WS/SS
MVJC	Journal Club on Environmental Physics	2	WS/SS

Code: MVEnv1 (Master module)		Course Title: Atmospheric Physics		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 3	Workload: 90 h	Teaching Hours: 3/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Atmospheric Physics“ (2 hours/week) • Exercise with homework (1 hour/week) Module Contents: <ul style="list-style-type: none"> • 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: Each part: 1-hour written exam				

Code: MVEnv2 (Master module)		Course Title: Physics of Terrestrial Systems		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 3	Workload: 90 h	Teaching Hours: 3/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Soil Physics” (2 hours/week) • Exercise with homework (1 hour/week) Module Contents: <ul style="list-style-type: none"> • 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				
Necessary/useful Knowledge: Content of MKEP4 Recommended Literature: To be announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: Each part: 1-hour written exam				

Code: MVEnv3 (Master module)		Course Title: Physics of Aquatic Systems		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 3	Workload: 90 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Physics of Aquatic Systems” (2 hours/week) • Exercise with homework (1 hour/week) Module Contents: <ul style="list-style-type: none"> • 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				
Necessary/useful Knowledge: Content of MKEP4 Recommended Literature: To be announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: Each part: 1-hour written exam				

Code: MVEnv4 (Master module)		Course Title: Physics of Climate		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 3	Workload: 90 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Physics of the Climate System” (2 hours/week) • Exercise with homework (1 hour/week) Module Contents: <ul style="list-style-type: none"> • The Sun and its variability (orbital and solar physics) • Ocean and atmosphere in the climate system • Cryosphere and soil in the climate system • Radiative transfer and climate • Climate variability • Climate change • Past and present atmospheric structure, composition and circulation • Climate through the Earth’s history (past 4.5 Ga) Objective: Advanced understanding of the Climate System and its changes in the past				
Necessary/useful Knowledge: Content of MKEP4 Recommended Literature: To be announced by lecturer Specialties: Exercises with homework				
Form of Testing and Examination: Each part: 1-hour written exam				

Code: MVEnv5		Course Title: Practical Environmental Physics		
Program: 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: <ul style="list-style-type: none"> Field- and laboratory studies on different topics of Environmental Physics (1LP/CP per topic; see below) Module Contents: <p>The following topics are offered:</p> <ul style="list-style-type: none"> 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:				

3.6 Medical Physics

Table 15: Specialisation Medical Physics

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

Table 16: Specialisation Medical Physics; Specialised lectures and seminars

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

Modulecode	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	2	WS/SS
MVJC	Journal Club on Medical Physics	2	WS/SS

Code: MVMP1		Course Title: Medical Physics 1		
Program: Master of Science (Physics)		Type: Lecture with Exercises		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Basics of x-ray imaging and radiation therapy” (4 hours/week) • Exercise (2 hour/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • 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 <p>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.</p>				
<p>Necessary/useful Knowledge: Basics on electromagnetic interactions and Fourier transformations</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: Exercises with homework</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

Code: MVMP2		Course Title: Medical Physics 2		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 6	Workload: 180 h	Teaching Hours: 6	Mode: WPM	Term: WS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Medical Physics 2” (4 hours/week) • Exercise (2 hour/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • 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): <i>k</i>–space sampling techniques, fast MRI, functional MRI, spectroscopic imaging • Detection of weak signals, hyperpolarisation • Data analysis in diagnostic imaging, image reconstruction and segmentation <p>Objective: To provide a comprehensive introduction into morphological and physiological imaging and spin– and radioactive–tracer techniques.</p>				
<p>Necessary/useful Knowledge: detector physics, rf-electronics, image processing, basics of biochemistry.</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: Exercises with homework</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

3.7 Particle Physics

Table 17: Specialisation Particle Physics

Modulecode	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

Table 18: Specialisation Particle Physics; Specialised lectures and seminars

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

Modulecode	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
MVSem	Advanced Seminar on Particle Physics	2	WS/SS
MVJC	Journal Club on Particle Physics	2	WS/SS

Code: MVHE1		Course Title: Advanced Topics in Particle Physics		
Program: Master of Science (Physics)		Type: Lecture and Journal Club		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: WS/SS
<p>Module Parts :</p> <ul style="list-style-type: none"> • 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) <p>Module Contents:</p> <p>The focus of the lecture are the experimental tests of the building blocks of matter and their fundamental interactions:</p> <ul style="list-style-type: none"> • 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 <p>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.</p>				
<p>Necessary/useful Knowledge: Content of PEP5 (Bachelor), MKEP1 (Master)</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: Journal Club to discuss actual research topics</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

Code: MVHE2		Course Title: Physics of Particle Detectors		
Program: Physics (Master)		Type: Lecture, tutorial and exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 3/week	Mode: WPM	Term: SS
<p>Module Parts:</p> <ul style="list-style-type: none"> • 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 re- search area are discussed (1 hour/week) <p>Module Contents:</p> <p>Focus of the lecture is the physics and the layout of detector components used in modern particle physics experiments. Topics are</p> <ul style="list-style-type: none"> • Interaction of particles with matter • Scintillators and ToF detectors • Gas detectors • Silicon detectors • Calorimeters • Detector for particle identification • Large detector systems <p>Objective: Introduction of the detector techniques used in modern particle physics ex- periments. The tutorials, including exercises, provide the possibility for discussions.</p>				
Necessary/useful Knowledge: Content of PEP4, PEP5, PTP4				
Recommended Literature: announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MVHE3		Course Title: Standard Model of Particle Physics		
Program: Master of Science (Physics)		Type: Lecture with Exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
<p>Module Parts :</p> <ul style="list-style-type: none"> • Lecture on “Standard Model of Particle Physics” (4 hours/week) • Exercises with homework (2 hours/week) <p>Module Contents:</p> <p>The focus of the lecture are 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.</p> <p>The course will include the necessary relativistic quantum field theory but with emphasis on applications rather than formal details.</p> <p>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.</p>				
<p>Necessary/useful Knowledge: Content of PEP5 (Bachelor) or MKEP1 (Master), PTP4 (Bachelor), MKTP1 (Master)</p> <p>Recommended Literature: To be announced by lecturer</p> <p>Specialties: Exercises with homework</p>				
Form of Testing and Examination: To be defined by lecturer before beginning of course				

3.8 Theoretical Physics

Table 19: Specialisation Theoretical Physics

Modulecode	Module	LP/CP	Term
MVTheo1	Quantum Field Theory 1	8	WS
MVTheo2	Quantum Field Theory 2	8	SS
MVTheo3	General Relativity	8	SS
MVTheo4	Condensed Matter Theory	8	WS

Table 20: Specialisation Theoretical Physics; Specialised lectures and seminars

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

Modulecode	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	2	WS/SS
MVJC	Journal Club on Theoretical Physics	2	WS/SS

Code: MVTheo1		Course Title: Quantum Field Theory 1		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Quantum Field Theory 1” (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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 • Fermion Feynman rules • Path integral of fermions <p>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 Φ^4-theory and for simple reactions in QED.</p>				
Necessary/useful Knowledge: Content of PEP3, PTP4, MKTP1				
Recommended Literature: announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MVTheo2		Course Title: Quantum Field Theory 2		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Quantum Field Theory 2” (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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 <p>Objective: To have a clear understanding of the regularisation renormalisation program in Φ^4-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.</p>				
Necessary/useful Knowledge: Content of PEP3, PTP4, MVTheo1, MKTP1				
Recommended Literature: announced by lecturer				
Specialties: Exercises with homework				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MVTheo3		Course Title: General Relativity		
Program: Master of Science (Physics)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “General Relativity” (4 hours/week) • Exercise with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • 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: defined by lecturer before beginning of course				

Code: MVTheo4		Course Title: Condensed Matter Theory		
Program: Master of Science (Physics)		Type: Lecture with excersises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WPM	Term: SS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on Condensed Matter Theory (4 hours/week) • Exercise (2 hour/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • 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 <p>Depending on the lecturer more weight will be given to solid state theories or to soft matter.</p> <p>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.</p>				
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				

4. Options

In the options sector, students must acquire 24 CP, which can be obtained through selecting subjects in physics, subjects from an adjacent subject area, or subjects from the field of so-called „transferable skills“. In physics, all the modules already listed in the core or specialization sectors can also be taken as options (see chapters 2 and 3). In addition, modules offered by other departments can also 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's degree; in such cases, permission must be requested explicitly by applying to the Master's 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“ and „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's students can be found in detail in the guide to the Bachelor's degree.

Table 21: Personal Key Competences

Modulecode	Module	LP/CP	Term
UKTutor	Course for tutors and handling of tutorials	6	SS/WS

Table 22: Berufsbezogene Schlüsselkompetenzen

Modulecode	Module	LP/CP	Term
UKBEng	Block course: English for physicists (aliens only)	1	SS/WS
UKBI1	Block course: Programming in C++	1	SS/WS
UKBI2	Block course: Data analysis	1	SS/WS
UKBI3	Block course: Introduction to Linux	1	SS/WS

Table 23: Specific additional technical competences

Modulecode	Module	LP/CP	Term
<i>General technical competences</i>			
UKNum	Practical Course: Numerical Methods	3	WS
UKSta	Practical Course: Statistical Methods	3	SS
<i>Additional technical competences in mathematics</i>			
UKMath1	Higher course in analysis	8	WS
UKMath2	Introduction to numerical calculations	8	SS
UKMath3	Partial differential equations	8	
<i>Additional competences in scientific computation</i>			
UKWR1	Scientific computation 1	8	WS
UKWR2	Introduction to computer physics	6	SS
<i>Additional competences in electronics</i>			
UKEL1	Electronics and electronic laboratory course	7	WS
UKEL2	Microelectronics and electronic laboratory course	7	WS
<i>Additional competences in computer science</i>			
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
<i>Additional competences in chemistry</i>			
UKChe	General chemistry	12	SS/WS
<i>Additional competences in biology</i>			
UKBio	Fundamentals of cellular and molecular biology	8	WS
<i>Additional competences in economics</i>			
UKPö1a	Introduction to political economics	8	WS
UKPö1b	Corporate Governance	8	WS
UKPö2a	Macro economics	8	SS
<i>Additional competences in physiology</i>			
UKPhy			

* Modulecode

Table 24: Modules in Computer Science

Modulecode	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

Code: MWInf1 (Master module)		Course Title: Parallel Computer Architectures		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Parallel Computer Architectures “ (4 hours/week) • Exercises with homework(2 hours/week) Module Contents: <ul style="list-style-type: none"> • Concepts of parallel processing and programming • Communication and synchronization • Shared memory machines, cache coherence protocols, synchronization, case studies • Distributed Systems, message passing, synchronization, case studies • Latency tolerance, hiding • Interconnection networks, topologies, routing, protocols, cache coherence protocols, case studies • Cluster computing, network interfaces, distributed mass storage, fault tolerance • Hardware accelerators, FPGA co-processors, GPU • GRID computing, resource management, applications Objective: Programming message passing (MPI) and threads; understanding of parallel systems.				
Necessary/useful Knowledge: UKInf1, UKInf2 Recommended Literature: announced by lecturer Specialties: –				
Form of Testing and Examination: 2-hour written exam				

Code: MWInf2 (Master module)		Course Title: Digital Circuit Technology		
Program: Physics (Master)		Type: Lecture with exercises		
Credit Points: 8	Workload: 240 h	Teaching Hours: 6/week	Mode: WM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Digital Circuit Technology“ (4 hours/week) • Exercises with homework (2 hours/week) Module Contents: <ul style="list-style-type: none"> • Introduction, motivation, history • Diode, MOS structure, FET and BJT • Manufacturing technology • Inverter, gates and simple building block • Latches, flip-flops and clocked circuits, State machines • Advanced building blocks (Shifters, Counters, Adders, Multiplier) • Memory components • Logic styles (CMOS, pass gate, dynamic, differential, ...) • PALs, CPLDs und FPGAs • Introduction to hardware description with verilog... <p>Objective: Basic knowledge about the manufacturing and the functioning of digital circuits; ability to design digital circuits using schematic entry or Verilog; understanding of FPGAs; overview over some common logic families.</p>				
Necessary/useful Knowledge: Content of UKInf2				
Recommended Literature: announced by lecturer				
Specialties: –				
Form of Testing and Examination: 2-hour written exam				

Code: MWInf3 (Master module)		Course Title: Design of VLSI Circuits using VHDL		
Program: Physics (Master)		Type: Lecture with practical exercises		
Credit Points: 4	Workload: 120 h	Teaching Hours: 4/week	Mode: WM	Term: SS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Design of VLSI Circuits using VHDL“ (2 hours/week) • Practical Exercises (2 hours/week) Module Contents: <ul style="list-style-type: none"> • Motivation: Why automated Circuit Design? • Levels of Abstraction and Views • Target Technologies • Components of Digital Circuits • Optimization of Digital Circuits • VHDL Overview • Signals and Data Types • VHDL Operators • Parallel and Sequential Statements • Details about Sequential Statements • Finite State Machines in VHDL • VHDL and Synthesis of Digital Circuits • VHDL for the Design of FPGAs VHDL • VHDL in Commercial Designs Objective: Basics of the hardware description language VHDL; practical application to digital circuits.				
Necessary/useful Knowledge: Content of UKInf2, UKEL2 Recommended Literature: announced by lecturer Specialties: –				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MWInf4 (Master module)		Course Title: Embedded Systems		
Program: Physics (Master)		Type: Lecture with practical course		
Credit Points: 4	Workload: 120 h	Teaching Hours: 4/week	Mode: WM	Term: WS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on “Embedded Systems“ (2 hours/week) • Practical course (2 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Microcontroller • Input and Output Components • Memory • Busses • Examples of modern Microcontrollers • Reset and Initialization • Interrupts • Signal Processors • System Design and Synthesis tools • Processor IP • Linux for Embedded Systems • Linux Driver Development <p>Objective: Basic components and architecture of modern micro controller and micro computer systems; construction of memory and bus systems; application of the Linux operating system on micro controllers.</p>				
<p>Necessary/useful Knowledge: Content of UKInf2</p> <p>Recommended Literature: announced by lecturer</p> <p>Specialties: –</p>				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MWInf5 (Master module)		Course Title: Physics of Imaging		
Program: Physics (Master)		Type: Lecture		
Credit Points: 4	Workload: 120 h	Teaching Hours: 4/week	Mode: WM	Term: WS
Module Parts: <ul style="list-style-type: none"> • Lecture on “Physics of Imaging“ (4 hours/week) Module Contents: <ul style="list-style-type: none"> • Projective geometry, optics, wave optics, Fourier optics and lens aberrations • Radiometry of imaging • Methods of imaging: scanning electron microscopy, X-ray, EDX, FLIM, FRET, fluorescence imaging, near-field imaging • CCD and CMOS technology • Holography, ultrasound imaging, CT- computer tomography, magnetic resonance imaging... • Satellite imaging, synthetic aperture radar, radio astronomy Objective: Basics of the Physics of Imaging; common principles and techniques of imaging for atomic to astronomical scales.				
Necessary/useful Knowledge: Content of UKInf2, PEP1-PEP4 Recommended Literature: announced by lecturer Specialties: –				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MWInf6 (Master module)		Course Title: Image Processing		
Program: Physics (Master)		Type: Lecture and exercise		
Credit Points: 7	Workload: 210 h	Teaching Hours: 6/week	Mode: WM	Term: WS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on “Image Processing“ (4 hours/week) • Exercises (2 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Continuous and discrete signals, sampling theorem, signal representation • Fourier transform • Random variables and fields, probability density functions, error propagation • Homogeneous and inhomogeneous point operations • Neighbourhood operations, linear and nonlinear filters, linear system theory • Geometric transformations and interpolation • Multi-grid signal presentation and processing • Averaging, edge and line detection, local structure analysis, local phase and wave numbers • Motion analysis in image sequences • Segmentation • Regression, globally optimal signal analysis, variation approaches, steerable and nonlinear filtering, inverse filtering • Morphology and shape analysis, moments, Fourier descriptors • Bayesian image restoration • Object detection and recognition <p>Objective: Learn how to analyze signals from time series, images, and any kind of multidimensional signals and to apply it to problems in natural sciences, life sciences and technology.</p>				
<p>Necessary/useful Knowledge: Content of UKInf1</p> <p>Recommended Literature: B. Jähne, Digital Image Processing, 6th edition, Springer</p> <p>Specialities: –</p>				
Form of Testing and Examination: defined by lecturer before beginning of course				

Code: MWInf7 (Master module)		Course Title: Pattern Recognition		
Program: Physics (Master)		Type: Lecture and exercise		
Credit Points: 7	Workload: 210 h	Teaching Hours: 6/week	Mode: WM	Term: WS
<p>Module Parts:</p> <ul style="list-style-type: none"> • Lecture on “Pattern Recognition“ (4 hours/week) • Exercises (2 hours/week) <p>Module Contents:</p> <ul style="list-style-type: none"> • Curse of dimensionality • Variable selection and dimension reduction for high-dimensional data • Unsupervised learning: Cluster analysis • Supervised learning: Regression • Supervised learning: Classification by means of neural networks, support vector machines, etc. • Graphical models • Applications: Data mining, industrial quality control, process monitoring, astrophysics, medicine, life sciences <p>Objective: Given a huge bunch of data, find out what’s in it; build automated diagnostic systems or expert systems that automatically learn to make reliable predictions from a training set of examples. Lectures and exercises will be interwoven and allow you to build such systems by yourself; real-life examples will be drawn from for the application areas named above.</p>				
<p>Necessary/useful Knowledge: Content of UKInf1; Knowledge about Linear Algebra, Probability, Statistics</p> <p>Recommended Literature: Pattern Classification (2nd ed.) by Richard O. Duda, Peter E. Hart. and David G. Stork. Wiley, 2000.</p> <p>Specialties: –</p>				
Form of Testing and Examination: defined by lecturer before beginning of course				

5. Model study plans

In this chapter, we give a variety of possible model study plans which have different focus points. As more than two thirds 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's degree. The model study plans here should thus serve as an aid for orientation on what might be suitable. Students should inform themselves of the options at an early stage in planning their degree. The master's 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 is given in Tables 25 and 26 (Model study plans „Experimental Physics“); other model study plans with specific specialisations can otherwise be found in Table 27 ff. These may be an interesting option for students who already have decided on the field in which they would like to perform the research for their master's thesis. Almost all the model study plans contain a non-specific part which is not directly related to the envisaged field of research. The Department of Physics and Astronomy does not in general recommend a strong specialisation at the master's level.

Legende:

Kursprogramm:

MKTP1	Theoretical Quantum Statistics
MKTP2	Theoretical Astrophysics
MKEP1	Particle Physics
MKEP2	Condensed Matter Physics
MKEP3	Advanced Atomic ...
MKEP4	Environmental Physics
MKEP5	Observational Astronomy
MPr	Oral Master Exam
MFS	Scientific Specialisation
MFP	Methods and Project Planning
MFA	Master Thesis

Übergreifende Kompetenzen: [siehe auch BA-Handbuch]

UKBI1	Programmieren in C++
UKBI2	Datenanalyse
UKBI3	Einführung in Linux
UKBEng	Englisch für Physiker
UKNum	Numerical Methods
UKSta	Statistical Methods
UKInf1	Programmiermethoden ...
UKInf2	Technische Informatik
UKInf3	Informatikpraktikum
UKInf4	Algorithmen und Datenstr.

Spezialvorlesungen, Seminare:

MVSpec	Spezialvorlesung Physik aus einem Vertiefungsgebiet
MVSem	Advanced Seminar
MVJC	Journal Club
MWahl	Wahlfach aus Angebot einer anderen Fakultät

Specialisation Physik:

MVAMO1	Experimental Optics ...
MVAMO2	Theoretical Quantum Optics ...
MVAMO3	Ultracold Quantum Matter ...
MVAMO4	Stored Particles
MVAstro0	Introduction to Astronomy
MVAstro1	Observational Methods
MVAstro2	Stellar Astronomy & Astroph.
MVAstro3	Galactic & Extragal. Astroph.
MVAstro4	Cosmology
MVBio1	Introduction to Biophysics
MVBio2	Theoretical Biophysics
MVCMP1	Low Temperature Physics
MVCMP2	Surfaces and Nanostructures
MVEnv1	Atmospheric Physics
MVEnv2	Physics of Terrestrial Systems
MVEnv3	Physics of Aquatic Systems
MVEnv4	Physics of Climate
MVEnv5	Practical Environmental Phys.
MVMP1	Medical Physics 1
MVMP2	Medical Physics 2
MVHE1	Adv. Topics in Particle Phys.
MVHE2	Physics of Particle Detectors
MVHE3	Standard Model of Particle Ph.
MVTheo1	Quantum Field Theory 1
MVTheo2	Quantum Field Theory 2
MVTheo3	General Relativity
MVTheo4	Condensed Matter Theory

Informatik (Wahlbereich):

MWInf1	Parallel Computer Architect.
MWInf2	Digital Circuit Technology
MWInf3	Design of VLSI Circuits ...
MWInf4	Embedded Systems
MWInf5	Physics of Imaging
MWInf6	Image Processing
MWInf7	Pattern Recognition

**Table 25: Model study plan „Experimental Physics“
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8	MKEP2 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MKTP1 8 MVBio1 6	MVAstro4 6 MVSem 2 MVSpec 4		
Options.	UKBI1* 1 UKInf5* 7	UKBI2* 1 UKSta* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills”.

**Table 26: Model study plan „Experimental Physics“
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP3 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MKEP4 8 MVSem 2	MKTP1 8 MVSpec 4		
Options.	UKBI1* 1 UKInf2* 7	UKBI2* 1 UKNum* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills”.

**Table 27: Model study plan „Astronomy/Astrophysics“
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKTP2 8	MKEP5 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVAstro0 7 MVSpec 2 MVSem 2	MVAstro2 6 MVAstro4 6 MVSpec 2		
Options.	UKWR1 8 UKNum 3	MVJC 2		
Total CP	30	30	30	30

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

**Table 28: Model study plan „Astronomy/Astrophysics“
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP5 8 MKEP2 8	MKTP2 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVAstro4 6 MVSpec 2 MVSem 2	MVAstro0 7 MVAstro3 6		
Options.	UKBI3 1 UKSta 3	UKNum 3		
Total CP	30	30	30	30

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

**Table 29: Model study plan „Astronomy/Astrophysics“ “
[Continuation of the Bachelor study plan „Astronomy/Astrophysics“,
Commencement: winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKTP1 8	MKEP5 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVAstro3 6 MVCMP1 6 MVSPEC 2	MVAstro2 6 MVSem 2 MVSPEC 2		
Options.	UKWR1 8	UKTutor 6		
Total CP	30	30	30	30

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

**Table 30: Model study plan „Atomic, Molecular and Optical Physics“ (exp.)
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP3 8 MKEP1 8	MKEP2 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVAMO2 4 oder MVAMO4 4	MVAMO1 4 MVAMO3 4 MVSem 2		
Options.	UKInf1* 7 UKNum* 3	MVSPEC 4 MVJC 2		
Total CP	30	30	30	30

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

**Table 31: Model study plan „ Atomic, Molecular and Optical Physics“ (exp.)
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP3 8 MKEP1 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVAMO1 4 MVAMO3 4	MVAMO2 4 oder MVAMO4 4		
Options.	MWInf3 4 UKInf4* 7 UKSta* 3	MVSem 2 MVJC 2		
Total CP	30	30	30	30

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

**Table 32: Model study plan „Atomic, Molecular and Optical Physics“ (theo.)
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP3 8 MKTP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo1 8 MVAMO2 4 MVSem 2	MVSpec 4 MVSpec 4 MVSpec 3		
Options.		MVSpec 4 MVJC 2 UKInf2* 7		
Total CP	30	30	30	30

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

**Table 33: Model study plan „ Atomic, Molecular and Optical Physics“ (theoretical)
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP3 8 MKTP1 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MSem 2 MVSpec 3 MSpec 4	MVAMO2 4 MVSpec 4		
Options.	MVJC 2 MWInf3 4 UKInf4 7			
Total CP	30	30	30	30

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

**Table 34: Model study plan „Condensed Matter Physics“ (experimental)
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP3 8 MKTP1 8	MKEP2 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVCMP1 6 oder MVCMP2 6	MVSpec 4 MVSem 2		
Options.	MVTheo4 8	UKInf2* 7 UKSta* 3		
Total CP	30	30	30	30

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

**Table 35: Model study plan „Condensed Matter Physics“ (experimental)
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP3 8 MKTP1 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVSpec 6 MVSem 2 MVJC 2	MVCMP1 6 oder MVCMP2 6		
Options.	UKInf2* 7 UKSta* 3	MVSem 2		
Total CP	30	30	30	30

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

**Table 36: Model study plan „Condensed Matter Physics“ (experimental)
[Continuation of the Bachelor study plan „Kondensierte Materie“,
Commencement: winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP3 8 MKTP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo4 8 MVSpec 6	MVAMO7 3 MVSpec 6 MVSem 2		
Options.		MVSpec 8 UKSta 3		
Total CP	30	30	30	30

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

**Table 37: Model study plan „Medical Physics“
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8 MKEP3 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVMP1 6 MVSpec 4	MVMP2 6 MVSpec 6 MVSem 2		
Options.	UKBI1* 1 UKNum* 3	UKBI3* 1 UKSta* 3 UKWR2* 6		
Total CP	30	30	30	30

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

**Table 38: Model study plan „Medical Physics“
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP3 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVMP2 6 MVSpec 4 MVSem 2	MVMP1 6 MVSpec 6		
Options.	UKBI3* 1 UKSta* 3 UKWR2* 6	UKBI1* 1 UKNum* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“
Bereich „Übergreifende Kompetenzen“.

Table 39: Model study plan „Medical Physics“
[Continuation of the Bachelor study plan „Medizinphysik“,
Commencement: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8	MKEP2 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVBio1 6 MVSpec 4 MVSem 2	MVMP2 6 MVSpec 4 MVJC 2		
Options.	UKChe.1* 7 UKNum* 3	UKBEng* 1 UKSta* 3		
Total CP	30	30	30	30

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

**Table 40: Model study plan „Particle Physics“
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8 MKTP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVHE1 4	MVHE2 4 MVHE3 8 MVSem 2		
Options.	MVJC 2 MVTheo1 8	UKInf2* 7 UKNum* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“.

**Table 41: Model study plan „Particle Physics“
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKEP1 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVHE2 4 MVAstro4 6 MVSem 2	MKTP1 8 MVTheo1 8		
Options.	UKInf2* 7 UKNum* 3			
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“.

Table 42: Model study plan „Particle Physics“
[Continuation of the Bachelor study plan „Teilchenphysik“,
Commencement: winter semester]

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8	MPr 6 MKEP2 8	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo1 8 MVHE1 4	MVHE3 8 MVSem 2 MVJC 2		
Options.	UKInf1* 7 UKNum* 3	UKBI3* 1 UKSta* 3		
Total CP	30	30	30	30

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

**Table 43: Model study plan „Theory“ (Cosmology)
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKTP1 8 MKTP2 8	MKEP5 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo1 8 MVSem 2	MVTheo3 8 MVAstro4 6 MVJC 2		
Options.	UKBI3* 1 UKNum* 3			
Total CP	30	30	30	30

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

**Table 44: Model study plan „Theory“ (Condensed Matter)
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP2 8	MKTP1 8 MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo1 8 MVSpec 6	MVTheo4 8 MVSpec 6 MVSem 2		
Options.	UKMath2 8			
Total CP	30	30	30	30

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

**Table 45: Model study plan „Theory“ (Teilchenphysik)
[Continuation of the Bachelor study plan „Teilchenphysik (theoretisch)“,
Commencement: winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVTheo1 8 MVSpec 4 MVSpec 4	MVTheo2 8 MVHE3 8 MVSem 2		
Options.	UKTutor* 6	MVSpec 4 MVJC 2		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“.

**Table 46: Model study plan „Environmental Physics“
[Commencement in the winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP4 8 MKTP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MKEP3 8	MVEnv3 3 MVEnv4 3 MVEnv5 7		
Options.	MVSpec 3 UKNum* 3	MVSem 2 MVSpec 6 UKSta* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“.

**Table 47: Model study plan „Environmental Physics“
[Commencement in the summer semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP4 8 MKEP2 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation		MVEnv1 3 MVEnv2 3 MVEnv5 7		
Options.	MVSpec 4 UKBI3* 1 UKSta* 3	MVSem 2 MVSpec 6 UKNum* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“.

**Table 48: Model study plan „ Environmental Physics “
[Continuation of the Bachelor study plan „Umweltphysik“,
Commencement: winter semester]**

Study block	1st Semester	2nd Semester	3rd Semester	4th Semester
Core and mandatory courses	MKEP3 8 MKTP1 8	MPr 6	MFS 15 MFP 15	MFA 30
Specialisation	MVSpec 6	MVSem 2 MVEnv3 3 MVEnv4 3 MVEnv5 6		
Options.	UKChe.1* 7 UKNum* 3	MVSpec 2 UKChe.2* 5 UKSta* 3		
Total CP	30	30	30	30

* If not already completed during the course of the Bachelor's programme; otherwise replaced with courses from the sector „transferable Skills“..