

Description of Module Master of Science

128 Physics

PO-Version 2016

FRIEDRICH-SCHILLER-
UNIVERSITÄT
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Note :

Please note that you can find the information on examinations, courses corresponding to the examinations, and examination dates in the portal Friedolin under the menu item 'Browse module descriptions'. After logging in, please choose your degree, your study programme, and respective module. Any immediate changes made will be displayed promptly.

Modul BA-Phi 1.1 Introduction to Philosophy	
Module code	BA-Phi 1.1
Module title (German)	Einführung in die Philosophie
Module title (English)	Introduction to Philosophy
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	10 CP
Work load:	300 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	240 h

Modul BA-Phi 1.2 Formal and Informal Logic	
Module code	BA-Phi 1.2
Module title (German)	Logik und Argumentationslehre
Module title (English)	Formal and Informal Logic
Frequency of offer (how often is the module offered?)	Every second semester
Duration of module	1 semester
ECTS credits	10 CP
Work load:	300 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	240 h

Modul BW10.1 Basic Module Operations Management	
Module code	BW10.1
Module title (German)	Basismodul Operations Management
Module title (English)	Basic Module Operations Management
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW11.1 Basic Module Principles of Marketing Management	
Module code	BW11.1
Module title (German)	Basismodul Grundlagen des Marketing-Management
Module title (English)	Basic Module Principles of Marketing Management
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW12.2 Basic Module Corporate Finance	
Module code	BW12.2
Module title (German)	Basismodul Corporate Finance
Module title (English)	Basic Module Corporate Finance
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW12.2a Basic Module Investments, Finance and Capital Markets	
Module code	BW12.2a
Module title (German)	Basismodul Investition, Finanzierung und Kapitalmarkt
Module title (English)	Basic Module Investments, Finance and Capital Markets
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW15.1 Basic Module Accounting	
Module code	BW15.1
Module title (German)	Basismodul Buchführung
Module title (English)	Basic Module Accounting
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	3 CP
Work load:	90 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	30 h

Modul BW15.2 Basic Module Financial and Managerial Accounting	
Module code	BW15.2
Module title (German)	Basismodul Rechnungslegung und Controlling
Module title (English)	Basic Module Financial and Managerial Accounting
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW16.1 Basic Module Management	
Module code	BW16.1
Module title (German)	Basismodul Management
Module title (English)	Basic Module Management
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul BW20.1 Basic Module Microeconomics	
Module code	BW20.1
Module title (German)	Basismodul Mikroökonomik
Module title (English)	Basic Module Microeconomics
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying	90 h
(incl. preparations for examination)	

Modul BW21.1 Basic Module Macroeconomics	
Module code	BW21.1
Module title (German)	Basismodul Makroökonomik
Module title (English)	Basic Module Macroeconomics
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	90 h

Modul BW34.1 Basic Module Introduction to Business Economics	
Module code	BW34.1
Module title (German)	Basismodul Einführung in die Betriebswirtschaftslehre
Module title (English)	Basic Module Introduction to Business Economics
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-IN0036 Pattern Recognition	
Module code	FMI-IN0036
Module title (German)	Mustererkennung
Module title (English)	Pattern Recognition
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-IN0046 Computer Vision I	
Module code	FMI-IN0046
Module title (German)	Rechnersehen I
Module title (English)	Computer Vision I
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-IN0075 Object-oriented Programming	
Module code	FMI-IN0075
Module title (German)	Objektorientierte Programmierung
Module title (English)	Object-oriented Programming
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	90 h

Modul FMI-MA0207 Higher Analysis I	
Module code	FMI-MA0207
Module title (German)	Höhere Analysis 1
Module title (English)	Higher Analysis I
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	9 CP
Work load:	270 h
- In-class studying	90 h
- Independent studying	180 h
(incl. preparations for examination)	

Modul FMI-MA0243 Complex Analysis 1	
Module code	FMI-MA0243
Module title (German)	Funktionentheorie 1
Module title (English)	Complex Analysis 1
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-MA0406 Classical Differential Geometry - 9 CP	
Module code	FMI-MA0406
Module title (German)	Klassische Differentialgeometrie - 9 LP
Module title (English)	Classical Differential Geometry - 9 CP
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
ECTS credits	9 CP
Work load:	270 h
- In-class studying	90 h
- Independent studying (incl. preparations for examination)	180 h

Modul FMI-MA0445 Mathematical methods of classical mechanics - 6 CP	
Module code	FMI-MA0445
Module title (German)	Mathematische Methoden der klassischen Mechanik - 6 LP
Module title (English)	Mathematical methods of classical mechanics - 6 CP
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-MA0446 Classical differential geometry	
Module code	FMI-MA0446
Module title (German)	Klassische Differentialgeometrie - 6 LP
Module title (English)	Classical differential geometry
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	120 h

Modul FMI-MA1212 Higher Analysis 2	
Module code	FMI-MA1212
Module title (German)	Höhere Analysis 2
Module title (English)	Higher Analysis 2
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
ECTS credits	9 CP
Work load:	270 h
- In-class studying	90 h
- Independent studying (incl. preparations for examination)	180 h

Modul MC2.1.8 Theoretical Chemistry I	
Module code	MC2.1.8
Module title (German)	Theoretische Chemie I
Module title (English)	Theoretical Chemistry I
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	6 CP
Work load:	180 h
- In-class studying	105 h
- Independent studying	75 h
(incl. preparations for examination)	

Modul MC3.1.8 Theoretical Chemistry II	
Module code	MC3.1.8
Module title (German)	Theoretische Chemie II
Module title (English)	Theoretical Chemistry II
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	12 CP
Work load:	360 h
- In-class studying	225 h
- Independent studying	135 h
(incl. preparations for examination)	

Modul MedPhoA1.2 Optical Engineering	
Module code	MedPhoA1.2
Module title (German)	Optical Engineering
Module title (English)	Optical Engineering
Person responsible for the module	Herbert Gross, Michael Kempe, Maria Dienerowitz
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	--
Prerequisite for what other modules	This module is part of the block „Adjustment“ of the 1st semester.
Type of module (compulsory module, required elective module, elective module)	The module is mandatory for students not having a Bachelor degree in physics. Students of physics having passed the corresponding modules during their studies do not need to participate in this course.
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lectures: 2h/week exercises: 1h/week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<ul style="list-style-type: none"> • Introduction to optics • Geometrical optics: postulates of ray optics, paraxial optics, matrix approach, raytracing • Simple optical components: lenses, mirrors, stops • Wave optics: postulates of wave optics, relation between wave optics and ray optics • Optical imaging: field and pupil, magnification, lens maker's formula, afocal systems • Photometry and illumination, color • Optical instruments • Image quality: primary aberrations, wave aberrations, correction of systems • Beam optics: the Gaussian beam, transmission of a Gaussian beam through optical components, beam shaping • Optical properties of materials: metals, ceramics, glass, polymers and composites • Electromagnetic optics: electromagnetic theory of light, dielectric media, elementary electromagnetic waves, absorption and dispersion • Optical components II: Fibers, prisms, sensors, aspheres, arrays • Special topics: scanning, adaptive optics, gradient index optics
Intended learning outcomes	<p>This module provides an introduction into the fundamentals of optics and photonics which are necessary to understand optical phenomena in modern science and technology.</p> <p>Topics include an introduction into the theory of light (ray optics, wave optics, electromagnetic optics, photon optics), the theory of interaction of light with matter and the theory of semiconductor materials and their optical properties.</p>
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	written examination at the end of the semester
Additional information on the module	<p>Used media:</p> <p>Lectures/exercises: blackboard, projector</p>
Recommended reading	<ul style="list-style-type: none"> • E. Hecht: Optics, 4th ed., Addison-Wesley 2001 • B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics 2nd ed., Wiley 2007.
Language of instruction	English

Modul PAFBX411 Computational Physics II	
Module code	PAFBX411
Module title (German)	Computational Physics II
Module title (English)	Computational Physics II
Person responsible for the module	Prof. Dr. B. Brüggmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Computational Physics I PAFBU311 Theoretische Mechanik PAFBT211 Elektrodynamik PAFBT311
Type of module (compulsory module, required elective module, elective module)	039 M.Sc. Geosciences, required elective module 128 M.Sc. Physics focus „Quantum and Gravitational Theory“ 128 B.Sc. Physics, required elective module 679 B.Sc. Applied Computer Science, Application subject physics 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 hours/week Exercise: 2 hours/week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to Unix and higher-level programming languages (e.g.: C/C++ , Fortran) Numerical solution of partial differential equations Monte Carlo method Molecular dynamics methods Minimization problems
Intended learning outcomes	Teaching the basic algorithms and practical skills for the numerical solution of complex physical problems and Visualization of large amounts of data
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written examination
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFBX511 Introduction to Astronomy	
Module code	PAFBX511
Module title (German)	Einführung in die Astronomie
Module title (English)	Introduction to Astronomy
Person responsible for the module	Prof. Dr. A. Krivov
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	60 h
- Independent studying	60 h
(incl. preparations for examination)	

Modul PAFBX521 Relativistic Physics	
Module code	PAFBX521
Module title (German)	Relativistische Physik
Module title (English)	Relativistic Physics
Person responsible for the module	Prof. Dr. R. Meinel
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	60 h
- Independent studying	60 h
(incl. preparations for examination)	

Modul PAFLA017 Milky Way Galaxy	
Module code	PAFLA017
Module title (German)	Milchstraßensystem
Module title (English)	Milky Way Galaxy
Person responsible for the module	apl. Prof. K. Schreyer
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Introduction to astronomy
Prerequisite for what other modules	none
Type of module (compulsory module, required elective module, elective module)	33 LAG/LAR Astronomy: Required elective module 128 M.Sc. Physics: Required elective module (Specialization in „Astronomy/Astrophysics“)
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Structure and kinematics of the star system, basic equation of stellar statistics, environment of the sun • Large-scale motions of stars and interstellar matter, galactic rotation, Oort's constants, concepts of spiral structure • Star clusters and populations, satellite systems, formation and future of the Milky Way

Intended learning outcomes	<ul style="list-style-type: none">• Structure and kinematics of the star system, basic equation of stellar statistics, environment of the sun• Large-scale motions of stars and interstellar matter, galactic rotation, Oort's constants, concepts of spiral structure• Star clusters and populations, satellite systems, formation and future of the Milky Way• The students can independently work on exercises in the field.
Language of instruction	usually German

Modul PAFLX811 Continuum Mechanics	
Module code	PAFLX811
Module title (German)	Kontinuumsmechanik
Module title (English)	Continuum Mechanics
Person responsible for the module	Prof. Dr. R. Meinel
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Kinematics of deformable bodies (Lagrangian and Eulerian representation, trajectories and stream lines, local and substantial time derivative, divergence and rotation, two-dimensional potential flows) • Strain tensor and strain rate tensor (displacement field, volume dilatation and shear) • Balance equations (equation of continuity, momentum balance and stress tensor, balance of angular momentum and energy) • Constitutive equations (fluids, isotropic elastic solids) • Hydrodynamics (basic equations, Navier-Stokes equation, Euler equation, Bernoulli equation, sound waves, Hagen-Poiseuille flow, Helmholtz's theorems) • Linear theory of elasticity (elastostatics, elastic waves)
Intended learning outcomes	<ul style="list-style-type: none"> • Profound understanding of the basics and methods of continuum mechanics • Developing the capability to solve problems within this subject

Modul PAFMA001 Stellar Physics	
Module code	PAFMA001
Module title (German)	Physik der Sterne
Module title (English)	Stellar Physics
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/Astrophysics“ Compulsory module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 h per week Exercise 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	Formation and evolution of stars as a function of mass through the Hertzsprung-Russell diagram, stellar atmospheres, spectroscopy, photometry, nuclear fusion as an energy source
Intended learning outcomes	<ul style="list-style-type: none"> • Imparting the basic concepts, phenomena and concepts of stellar physics • Development of self-solve skills • Problems and problems of stellar physics
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or assessment of exercise sheets (100%)
Recommended reading	<ul style="list-style-type: none"> • Scheffler, Elsässer, Physik der Sterne und der Sonne (BI) • Carroll, Ostlie, Introduction to Modern Astrophysics (Addison-Wesley), • Stahler, Palla, The formation of stars (Wiley-VCH, 2004), • Unsöld, Baschek, Der neue Kosmos (Springer)
Language of instruction	German, English

Modul PAFMA002 Astronomical Observing Techniques	
Module code	PAFMA002
Module title (German)	Astronomische Beobachtungstechnik
Module title (English)	Astronomical Observing Techniques
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to Astronomy and Stellar Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Compulsory module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • radiation theory, luminosity • CCD detectors, data reduction • Structure and function of optical and infrared telescopes • Fundamentals of infrared astronomy • Speckle technique, Adaptive Optics, Interferometry • Radio Astronomy: Telescopes and Science • Ultraviolet, X-ray and gamma astronomy
Intended learning outcomes	Methods of observational astronomy in all wavelengths; Observation technology and data evaluation. Knowledge of telescope technology in all wavelengths
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or assessment of exercise sheets (100%)

Recommended reading	<ul style="list-style-type: none">• Karttunen, Kröger, Oja, Poutanen, Donner, Astronomie – eine Einführung (Springer)• Unsöld, Baschek, Der neue Kosmos (Springer)• Weigert, Wendker, Wisotzki, Astronomie und Astrophysik: ein Grundkurs (Wiley VCH)
Language of instruction	German, English

Modul PAFMA003 Celestial Mechanics	
Module code	PAFMA003
Module title (German)	Himmelsmechanik
Module title (English)	Celestial Mechanics
Person responsible for the module	Prof. Dr. A. Krivov
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Compulsory module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 2 h per week exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Subject of celestial mechanics; • two-body problem; • restricted three-body problem; • perturbed motion; N-planet problem; • resonant, secular, and periodic perturbations; • chaos und stability; • modern generalisations: relativistic celestial mechanics, nongravitational celestial mechanics, astrodynamics
Intended learning outcomes	<ul style="list-style-type: none"> • Learning the basic concepts, problems, and methods of both classical and modern celestial mechanics and its applications to astrophysical problems; • acquiring ability of solving relatively simple problems without the help of an instructor
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or exercise assessment (100%)
Additional information on the module	

Recommended reading	<ul style="list-style-type: none">• Murray, Dermott: Solar System Dynamics (Cambridge Univ. Press)• Danby: Fundamentals of Celestial Mechanics (Willmann-Bell)
Language of instruction	English

Modul PAFMA004 Astronomical Practicum	
Module code	PAFMA004
Module title (German)	Astronomisches Praktikum
Module title (English)	Astronomical Practicum
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to Astronomy and Stellar Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Compulsory module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 1 h per week Labwork 3 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Spectroscopy and photometry at the telescope • interstellar dust, • star formation • Infrared Astronomy • neutron star kinematics
Intended learning outcomes	Functioning and observation of stars, dust lab experiments , data analysis, error calculation
Prerequisites for admission to the module examination	Development of the protocols (Scope will be announced at the beginning of the module)
Requirements for awarding credit points (type of examination)	Module grade (100%)
Recommended reading	<ul style="list-style-type: none"> • Voigt, Abriss der Astronomie (BI Wissenschaftsverlag) • Unsöld, Baschek, Der neue Kosmos (Springer) • Scheffler, Elsässer, Physik der Sterne und der Sonne (BI) • Carroll, Ostlie, Intro to Modern Astrophysics (Addison-Wesley)
Language of instruction	English, German

Modul PAFMA005 Physics of Planetary Systems	
Module code	PAFMA005
Module title (German)	Physik der Planetensysteme
Module title (English)	Physics of Planetary Systems
Person responsible for the module	Prof. Dr. A. Krivov
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 4 h per week exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	Part I „Detection and Properties“ (Prof. Artie Hatzes): Exoplanet detection methods (radial velocity, astrometry, transits, direct imaging, microlensing, interferometry); properties and diversity of planetary systems inferred from observations; Part II „Formation and Evolution“ (Prof. Alexander Krivov): planet formation theory (accretion disks, dust-gas interactions, agglomeration of dust to planetesimals, planetesimal growth and embryo formation, formation of gas giants and terrestrial planets, migration, debris disks); evolution of planetary systems
Intended learning outcomes	Getting familiar with the properties, formation scenarios and evolutionary pathways of the Solar System and extra-solar planetary systems Acquiring ability of solving relatively simple problems without the help of an instructor
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%)

Recommended reading	<ul style="list-style-type: none">• Safronov, Evolution of the protoplanetary cloud and formation of the Earth and the planets• Armitage: Astrophysics of Planet Formation (Cambridge University Press)• "Protostars and Planets III-VI" (Univ. Arizona Press)
Language of instruction	English

Modul PAFMA006 Terra Astronomy	
Module code	PAFMA006
Module title (German)	Terra-Astronomie
Module title (English)	Terra Astronomy
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to Astronomy and Stellar Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 2 h per week exercise: 2 h per week seminar: 2h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Solar activity and wind • cosmic radiation and its sources • Supernovae and their remains • neutron stars • Gamma-ray bursts • Radionuclides on Earth • impact of cosmic events on earth and biosphere, • Historical observations on the reconstruction of solar activity and cosmic explosions
Intended learning outcomes	<ul style="list-style-type: none"> • Understanding the basic concepts, phenomena and concepts of terra astronomy • Ability to solve problems in terra-astronomy independently • development of presentation skills in one of the subareas
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or assessment of exercise (100%)
Additional information on the module	every 4 semester

Recommended reading	Solar physics textbooks (e.g., Vaquero & Vasquez) and supernovae textbooks (e.g., Stephenon & Green)
Language of instruction	German, English

Modul PAFMA007 Neutron Stars	
Module code	PAFMA007
Module title (German)	Neutronensterne
Module title (English)	Neutron Stars
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Introduction to Astronomy and Stellar Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 2 h per week exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • evolution of stars as a function of mass, • After main series development, • End stages: white dwarfs, Neutron stars, black holes, supernovae remnants, • High energy astrophysics: X-ray and gamma radiation
Intended learning outcomes	Development of stars of different masses, final stages, methods of high-energy astrophysics
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or assessment of exercise (100%)
Recommended reading	<ul style="list-style-type: none"> • Unsöld, Baschek, Der neue Kosmos (Springer) • Scheffler, Elsässer, Physik der Sterne und der Sonne (BI) • Longair, High Energy Astrophysics vol. 1 & 2 (Cambridge) • Lorimer, Kramer, Handbook of Pulsar Astronomy (Cambridge) • Haensel, Potekhin, Yakovlev, Neutron stars (Springer)
Language of instruction	German, English

Modul PAFMA010 Introduction to Radio Astronomy	
Module code	PAFMA010
Module title (German)	Einführung in die Radioastronomie
Module title (English)	Introduction to Radio Astronomy
Person responsible for the module	Apl. Prof. Dr. K. Schreyer, Dr. M. Hoeft
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second year (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 2 h per week exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> basics of radio astronomy, Overview of concepts, methods and techniques of modern radio telescopes and observations, Exemplary presentation of current topics of research with these telescopes
Intended learning outcomes	<ul style="list-style-type: none"> teaching basic concepts, phenomena and concepts of radio astronomy (submm to meter wavelengths), Abilities to prepare, perform and evaluate own observations with a radio telescope
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%)
Recommended reading	<ul style="list-style-type: none"> Rohlfs: „Tools of Radio Astronomy“ (Springer) Burke, Graham-Smith: „An introduction to radio astronomy“ (Cambridge Univ. Press) Thompson: „Interferometry and synthesis in radio astronomy“ (Wiley) Wilson: „Tools of radio astronomy: problems and solutions“ (Springer)

Language of instruction	German, English
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Modul PAFMA011 The Solar System	
Module code	PAFMA011
Module title (German)	Das Sonnensystem
Module title (English)	The Solar System
Person responsible for the module	Dr. habil. T. Löhne
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lecture: 2 h per week exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • overview and historical outline; • Earth-like planets; • Small bodies: asteroids and comets; • solar wind and magnetic fields; • Interplanetary medium and meteoroids; • surface modifications; • Age determination; • gas and ice giants; • moons and rings; • Element distribution; • development; • Habitability and comparison with extrasolar systems
Intended learning outcomes	<ul style="list-style-type: none"> • knowledge of the structure and evolution of the solar system and its components; • Understanding the essential physical processes, relationships, models and measurement methods; • Develop skills to solve simple tasks in these areas on their own
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written or oral examination (100%)
Recommended reading	<ul style="list-style-type: none">• Weissman u.a. (Hrsg.): Encyclopedia of the Solar System (Academic Press)• Encrenaz u.a.: The Solar System (Springer)• Gürtler, Dorschner: Das Sonnensystem (Barth)• de Pater, Lissauer: Planetary Sciences (Cambridge U. Press)• Jones: Discovering the Solar System (Wiley)
Language of instruction	German, English

Modul PAFMA014 Cosmology	
Module code	PAFMA014
Module title (German)	Kosmologie
Module title (English)	Cosmology
Person responsible for the module	Prof. Dr. H. Cartarius, Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules General Relativity and/or Extragalactic Astrophysics
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 3 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 75 h 105 h
Content	<ul style="list-style-type: none"> • Robertson-Walker universes; • Friedman's world models; • Cosmologically relevant astronomical observations; • models with cosmological constant; • horizons; • Inflation; • Thermal history of the early universe; • Structure formation.
Intended learning outcomes	The student knows the problems, methods and statements of modern theoretical and observational cosmology. He is able to read up-to-date specialist literature in an understanding manner and independently solve exercise tasks for the specified areas.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	<ul style="list-style-type: none">• Schneider, Extragalaktische Astronomie (Springer);• Harrison: Cosmology (Cambridge University Press);• Goenner: Einführung in die Kosmologie (Spektrum Akademischer Verlag).
Language of instruction	German, English

Modul PAFMA015 History of Astronomy	
Module code	PAFMA015
Module title (German)	Historische Astronomie
Module title (English)	History of Astronomy
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“ Required elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week Seminar: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Bedeutung der Astronomie als treibende Kraft für die Entwicklung der Physik Praktische (rechnende wie beobachtende) Astronomie von der Steinzeit bis heute • Lernen auf historischen Erkenntniswegen: Replikation von historischen Versuchen, Beobachtungen, Rechnungen, Fehleranalysen sowie Quellenstudium • Möglicherweise Programmierarbeiten
Intended learning outcomes	<ul style="list-style-type: none"> • Kenntnisse der Geschichte der Astronomie • Experimentelle und rechnerische Übungen, Schulung in verschiedenen Denkstilen und Fertigkeiten • Arbeiten mit historischen Daten
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Additional information on the module	ggf. archäoastronomische Exkursion möglich
Recommended reading	<ul style="list-style-type: none"> • James Evans: The History and Practise of Ancient Astronomy, 1998 • D. Kelley; E. Milone: Exploring Ancient Skies: A Survey of Ancient and Cultural Astronomy, 2011 • K. Simonyi: Kulturgeschichte der Physik, 2001
Language of instruction	German, English on request

Modul PAFMA016 Extragalactic Astrophysics	
Module code	PAFMA016
Module title (German)	Extragalaktik
Module title (English)	Extragalactic Astrophysics
Person responsible for the module	Dr. M. Hoeft
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Milky Way system: components of the star system, kinematics of the stars; • Galaxies: normal and active galaxies, supermassive black holes, galaxy clusters; • Observational cosmology: distance determination, supernovae, gamma-ray bursts, background radiation, world models, dark matter.
Intended learning outcomes	<ul style="list-style-type: none"> • understanding the basic concepts, phenomena and concepts of observational extra-galactics; • Understanding extragalactic and cosmological phenomena.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	<ul style="list-style-type: none"> • Schneider, Extragalaktische Astronomie (Springer) • Unsoeld & Baschek, Der neue Kosmos (Springer)
Language of instruction	German, English

Modul PAFMA017 Helio- and Asteroseismology	
Module code	PAFMA017
Module title (German)	Helio- und Asteroseismologie
Module title (English)	Helio- and Asteroseismology
Person responsible for the module	Prof. Dr. M. Roth
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	PAFBX511 Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Overview on internal structure and evolution of the stars • Types of stellar pulsations • Theoretical description of stellar oscillations • Observational techniques • Spectral analysis • Inversion methods • Global and local techniques of solar seismology • Seismology on stars
Intended learning outcomes	The lecture enables students to understand the theory, methods and modern observation procedures of helio- and asteroseismology. After completing the course, students are able to describe and classify the internal structure of the Sun and stars as well as the processes taking place in these celestial bodies and to make well-founded statements based on scientific data. They also develop the ability to carry out their own research in the field of helio- and asteroseismology, i.e. to develop theoretical models and analyze data.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester

Requirements for awarding credit points (type of examination)	Oral examination (100%). The details will be announced at the beginning of the semester.
Recommended reading	Conny Aerts et al., "Astero-seismology" William Chaplin, "Music of the Sun" Joergen Christensen Dalsgaard, "Lecture Notes on Stellar Oscillations" Frank Pijpers, "Methods of helio- and astero-seismology"
Language of instruction	German, English

Modul PAFMA098 Current Research in Astronomy	
Module code	PAFMA098
Module title (German)	Aktuelle Forschung in der Astronomie
Module title (English)	Current Research in Astronomy
Person responsible for the module	Prof. Dr. A. Krivov
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/ Astrophysics“
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Further, in-depth topics in the field of astronomy; • Topics from current areas of research.
Intended learning outcomes	<ul style="list-style-type: none"> • deepening into a special field of astronomy; • Independent handling of exercises; • ability to independently search literature.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	German, English

Modul PAFMA099 Current Research in Astrophysics	
Module code	PAFMA099
Module title (German)	Aktuelle Forschung in der Astrophysik
Module title (English)	Current Research in Astrophysics
Person responsible for the module	Prof. Dr. R. Neuhäuser
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physics focus „Astronomy/Astrophysics“
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	<ul style="list-style-type: none"> • Further, in-depth topics in the field of astrophysics; • Topics from current areas of research.
Intended learning outcomes	<ul style="list-style-type: none"> • specialisation in a special field of astrophysics; • Independent handling of exercises; • Ability to independently search literature.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	German, English

Modul PAFMF001 Theoretical Solid State Physics	
Module code	PAFMF001
Module title (German)	Theoretische Festkörperphysik
Module title (English)	Theoretical Solid State Physics
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics, required elective module, focus „Solid state physics / Material science“ 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Crystal structures and elastic properties of solids; • Electronic properties of crystals; • Approximate methods for electronic band structure; • Semiconductors and defect physics; • P-n junctions; • Microscopic description of charge transport; • Properties of alloys; • Nanostructures and interfaces; • Optical and dielectric properties of solids; • Magnetism and superconductivity.
Intended learning outcomes	The course covers advanced topics of solid state physics, with a specific focus on the theoretical understanding of the properties of electrons in crystals. An effort is made to remain as rigorous as possible in the theoretical and mathematical treatment, while keeping the presentation at an accessible level through the presentation of interesting applications to experiments and advanced technology. After completion of the course the students will master the relation between electronic structure of crystalline solids and their dielectric, optical, transport, magnetic properties.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written examination (100%)
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF002 Electronic Structure Theory	
Module code	PAFMF002
Module title (German)	Theorie der Elektronenstruktur
Module title (English)	Electronic Structure Theory
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 3 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 75 h 165 h
Content	Introduction to the many-body problem; Wavefunction-based approaches for electronic structure; Density functional theory; Electronic excitations: beyond density functional theory.
Intended learning outcomes	Electronic structure theory is a successful and ever-growing field, shared by theoretical physics and theoretical chemistry, that takes advantage from the increasing availability of high-performance computers. Starting only from the knowledge of the types of atoms that constitute a material (molecule, solid, nanostructure,...) students will learn how to determine without further experimental input, i.e. using only the laws of quantum physics, its structural and electronic properties. The lecture will initiate the students to the state-of-the-art theoretical and computational approaches used for electronic structure calculations. In the practical classes the students will learn through tutorials to use different software for electronic structure simulations. During the last month they will realize a small independent scientific project.

Prerequisites for admission to the module examination	Course exercises to be submitted; Further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc.Physics: Specialization "Solid state physics / Material science". If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF003 Solid State Optics	
Module code	PAFMF003
Module title (German)	Solid State Optics
Module title (English)	Solid State Optics
Person responsible for the module	Prof. Dr. H. Krüger
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology: Required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	2 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Introduction to the many-body problem; • Wavefunction-based approaches for electronic structure; • Density functional theory; • Electronic excitations: beyond density functional theory.
Intended learning outcomes	Electronic structure theory is a successful and ever-growing field, shared by theoretical physics and theoretical chemistry, that takes advantage from the increasing availability of high-performance computers. Starting only from the knowledge of the types of atoms that constitute a material (molecule, solid, nanostructure,..) we will learn how to determine without further experimental input, i.e. using only the laws of quantum physics, its structural and electronic properties. The lecture will initiate the students to the state-of-the-art theoretical and computational approaches used for electronic structure calculations. In the practical classes the students will learn through tutorials to use different software for electronic structure simulations. During the last month they will realize a small independent scientific project.

Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF006 Superconductivity	
Module code	PAFMF006
Module title (German)	Supraleitung
Module title (English)	Superconductivity
Person responsible for the module	apl. Prof. Dr. F. Schmidl
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics, Required elective module focus „Solid state physics / Material science“, 177 M.Sc. Materialwissenschaften, Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Basic effects of superconductivity; • characteristics of superconductors; • Josephson effects; • Superconducting materials (classes, structure, properties); • fabrication (single crystals, solid material, layers, wires, ribbons); • modification of the materials (doping, pinning); • Applications of superconductivity.
Intended learning outcomes	<ul style="list-style-type: none"> • Understanding the basic concepts and concepts of superconductivity, superconducting materials and their application; • creation of ready-to-use basic knowledge; • Ability to independently re-deepen the subject. • Ability to participate in a scientific discussion
Prerequisites for admission to the module examination	Active participation in discussions in the seminar and preparation of a term paper
Requirements for awarding credit points (type of examination)	Module grade: term paper and presentation (100%)
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMF007 Physics of Vacuum and Thin Films	
Module code	PAFMF007
Module title (German)	Vakuum- und Dünnschichtphysik
Module title (English)	Physics of Vacuum and Thin Films
Person responsible for the module	Prof. Dr. P. Seidel, apl. Prof. Dr. F. Schmidl
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Fundamentals of vacuum physics and their application in coating plants; • Vacuum technology; • overview of the thin film deposition process; • physics of stratification processes and layer growth; • structure-property relationships; • mechanical and electrical properties; • Thin film technologies; • Film analysis
Intended learning outcomes	<ul style="list-style-type: none"> • understanding the basic concepts and concepts of vacuum and thin-film physics; • Creation of basic knowledge ready for application.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%).
Language of instruction	German, English

Modul PAFMF009 Optoelectronics	
Module code	PAFMF009
Module title (German)	Optoelektronik
Module title (English)	Optoelectronics
Person responsible for the module	Prof. Dr. G. Soavi
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Semiconductors • Optoelectronic devices • Photodiodes • Light emitting diodes • Semiconductor optical amplifier
Intended learning outcomes	In this course the student will learn how to solve problems related to the fundamentals of semiconductor optical devices such as photodiodes, solar cells, LEDs, laser diodes and semiconductor optical amplifiers.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMF010 Ion Beam Modification of Materials	
Module code	PAFMF010
Module title (German)	Ionenstrahlphysik
Module title (English)	Ion Beam Modification of Materials
Person responsible for the module	Apl. Prof. E. Wendler
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Energy loss of the injected ions through nuclear and electronic interaction; • Effect of transmitted energy in the solid state (e.g., in semiconductors and ceramics); • Detection and modeling of damage formation and amorphization; • Application examples.
Intended learning outcomes	Students learn the basic terms, phenomena and concepts of ion-solid interaction. They will be able to realise the applications of ion beams for the modification of materials.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	<ul style="list-style-type: none"> • Nukleare Festkörperphysik (Schatz, Weidinger), • Ionenimplantation (Ryssel, Ruge), • Ion-Solid-Interactions (Nastasi, Mayer, Hirvonen), • High Energy Ion Beam Analysis (Götz, Gärtner).
Language of instruction	German, English

Modul PAFMF011 Graphene: Electronic and optical properties	
Module code	PAFMF011
Module title (German)	Graphene: Electronic and optical properties
Module title (English)	Graphene: Electronic and optical properties
Person responsible for the module	Prof. Dr. G. Soavi
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	1) Band structure of graphene and the Dirac Hamiltonian 1.1. Crystals in 2D 1.2. Tight binding of single layer graphene 1.3. Graphene field effect devices 1.4. Dirac equation 2) Dirac fermions and relativistic physics 2.1. Anomalous Quantum Hall Effect 2.2. Klein Tunneling 2.3. Effective mass and massless fermions 3) Optical properties 3.1. Phonons and Raman characterization 3.2. Absorption and visibility

Intended learning outcomes	We will first derive and study the basic electronic properties of graphene, including the linear electronic band dispersion (Dirac cone) and the ambipolar field effect. Subsequently we will discuss the pioneering experiments (years 2004-2010) that demonstrated the analogy between electrons in graphene and relativistic particles. Finally, we will examine the most relevant linear optical properties (Raman and absorption) of single layer graphene, and how to use them for optical characterization.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module -	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF012 Materials Informatics	
Module code	PAFMF012
Module title (German)	Materialinformatik
Module title (English)	Materials Informatics
Person responsible for the module	Prof. Dr. J. George
Type of module (compulsory module, required elective module, elective module)	128 MSc. Physics specialization solid-state physics/material science: required elective module 528 MSc. Quantum Science & Technology: Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 SWS Exercises: 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	Object-oriented programming and data science with Python, data sources and access to material data, automation of data generation (e.g. using density functional theory or machine-learned interatomic potentials), typical descriptors for materials (representation of the composition of crystalline or amorphous solids or the structure of crystalline solids), general principles of machine learning, classification and regression, supervised and unsupervised learning, clustering, kernel methods, neural networks (different architectures), current examples from materials informatics.
Intended learning outcomes	Students are familiar with the fundamental problems in materials informatics (focus on inorganic solid-state materials). They know basic concepts from the field of data science and machine learning and can apply methods from these fields to topics relating to materials and their data.
Prerequisites for admission to the module examination	Completion of the exercises (exact extend will be announced at the beginning of the module)
Requirements for awarding credit points (type of examination)	Oral examination or homework and presentation
Additional information on the module	Basic knowledge in Python is required
Recommended reading	Literature will be announced at the beginning of the semester
Language of instruction	English

Modul PAFMF015 Nuclear Solid State Physics	
Module code	PAFMF015
Module title (German)	Nukleare Festkörperphysik
Module title (English)	Nuclear Solid State Physics
Person responsible for the module	Prof. Dr. C. Ronning
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Mössbauer effect; • positron annihilation; • nuclear magnetic resonance; • muon spin rotation; • Ion beam analysis.
Intended learning outcomes	Students acquire in-depth knowledge in the field of solid state physics, which enables them to understand and work on corresponding problems.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or presentation (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	Schatz / Weidinger: „Nukleare Festkörperphysik“.
Language of instruction	German, English

Modul PAFMF016 Nanomaterials and Nanotechnology	
Module code	PAFMF016
Module title (German)	Nanomaterialien und Nanotechnologie
Module title (English)	Nanomaterials and Nanotechnology
Person responsible for the module	Prof. Dr. C. Ronning
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“ 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • dimension effects, • Quantisation of electrons • single-electron transistor, • synthesis of nanomaterials, • characterization of nanomaterials, • Material systems: carbon nanotubes, graphene, magnetic nanomaterials, bionanomaterials, • Application and technology of nanomaterials.
Intended learning outcomes	In-depth knowledge in the field of solid-state physics.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or presentation (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester
Language of instruction	English

Modul PAFMF018 Quantum Information Theory	
Module code	PAFMF018
Module title (German)	Quanteninformationstheorie
Module title (English)	Quantum Information Theory
Person responsible for the module	Prof. Dr. M. Gärttner
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Quantum mechanics, linear algebra
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module specialization "Quantum and Gravitational Theory" 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>Lecture of Drs. Eilenberger, Steinlechner</p> <ul style="list-style-type: none"> • Basic introduction to quantum optics; • Quantum light sources; • Encoding, • transmission and detection of information with quantum light; • Quantum communication and cryptography; • Quantum communication networks; • Outlook on Quantum metrology and Quantum imaging; <p>Lecture of Dr. Sondenheimer</p> <ul style="list-style-type: none"> • Open quantum systems, Density matrix formalism, Generalized measurements, Quantum channels • Superdense coding, quantum teleportation • Entanglement theory, Bell inequalities, • CHSH inequalities • Quantum circuits, universal gates • Quantum error correction
Intended learning outcomes	<p>The course will give a basic introduction into the usage of quantum states of light for the exchange of information. It will introduce contemporary methods for the generation of quantum light and schemes that leverage these states for the exchange of information, ranging from fundamental concepts and experiments to state of the art implementations for secure communication networks. The course will also give an outlook to aspects of Quantum metrology and imaging. After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.</p> <p>Vermittlung grundlegender Kenntnisse zur Übertragung und Verarbeitung von Information mit Hilfe von Quantensystemen als Informationsträger</p> <p>Informationstheoretische Beherrschung der Verschränktheit von Quantensystemen.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	<p>Written or oral examination (100%);</p> <p>The selected form of the exam will be announced at the beginning of the semester.</p>
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF019 Introduction to Material Science for Physicists	
Module code	PAFMF019
Module title (German)	Materialwissenschaft I
Module title (English)	Introduction to Material Science for Physicists
Person responsible for the module	Prof. Dr. K. D. Jandt
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Systematic presentation of materials science basics. • atomic structure and bonding types, • structure of metals and ceramics and polymers, • disturbances in the structure of solids, • Diffusion, • Mechanical properties of materials • Deformation and reinforcement mechanisms, failure
Intended learning outcomes	After successfully completing the module, the student masters or can name important basic terms, phenomena and procedures in materials science. In addition, he / she develops skills for independently solving problems and tasks in the field of materials science
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or presentation (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	<ul style="list-style-type: none"> • William D. Callister Jr, Fundamentals of Materials Science and Engineering – An integrated approach, 3rd Edition, John Wiley & Sons, Inc. New York 2009 • Alternativ: Werkstoffe 1 & 2. M. F. Ashby, D. R. H. Jones, Spektrum Akademischer Verlag Heidelberg 2006

Language of instruction	German, English
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Modul PAFMF020 Surface Science	
Module code	PAFMF020
Module title (German)	Oberflächenphysik
Module title (English)	Surface Science
Person responsible for the module	Dr. R. Forker
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus Solid State Physics
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Preparation of well-defined surfaces • Geometrical structure of surfaces • Adsorption, desorption, diffusion • Diffraction methods • Electronic structure of surfaces • Electron microscopy • Scanning probe methods • Electron spectroscopy • Optical spectroscopy
Intended learning outcomes	Students acquire basic knowledge of the surface physics of solids. They will acquire advanced knowledge of the diverse investigation methods for surface analysis and their applications. Students develop the ability to independently familiarise themselves with challenging, cross-method topics of current research in the field of surface physics.
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	Oral examination/oral presentation (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	English, German on request

Modul PAFMF021 2D materials	
Module code	PAFMF021
Module title (German)	Zweidimensionale Materialien
Module title (English)	2D materials
Person responsible for the module	Prof. Dr. G. Soavi
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Graphene: electrical and optical properties. Applications in electronic and optoelectronic. • Semiconducting 2D materials: Coulomb screening and the concept of excitons. Optical spectroscopy of excitons. Optoelectronic applications. • Heterostructures: electron and exciton interactions in layered heterostructures
Intended learning outcomes	<ul style="list-style-type: none"> • Mastering the basics and methods of two-dimensional materials • Ability to work independently on problems in the field of two-dimensional materials
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMF022 Materials Science II	
Module code	PAFMF022
Module title (German)	Materialwissenschaft II
Module title (English)	Materials Science II
Person responsible for the module	Prof. Dr. K. D. Jandt
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Modul PAFMF023 Many-Body Perturbation Theory	
Module code	PAFMF023
Module title (German)	Vielteilchen-Störungstheorie
Module title (English)	Many-Body Perturbation Theory
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Modul PAFMF098 Advanced Solid State Physics I	
Module code	PAFMF098
Module title (German)	Vertiefung Festkörperphysik I
Module title (English)	Advanced Solid State Physics I
Person responsible for the module	Prof. Dr. C. Ronning
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise/seminar: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Systematic development of specialized knowledge in the fields of solid state physics and materials science.
Intended learning outcomes	In-depth knowledge in the fields of solid state physics and materials science.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or presentation (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	German, English

Modul PAFMF099 Advanced Solid State Physics II	
Module code	PAFMF099
Module title (German)	Vertiefung Festkörperphysik II
Module title (English)	Advanced Solid State Physics II
Person responsible for the module	Prof. Dr. C. Ronning
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise/seminar: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Systematic development of specialized knowledge in the fields of solid state physics and materials science.
Intended learning outcomes	In-depth knowledge in the fields of solid state physics and materials science.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or presentation (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	German, English

Modul PAFMM250 Metallic materials	
Module code	PAFMM250
Module title (German)	Metallische Werkstoffe
Module title (English)	Metallic materials
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying (incl. preparations for examination)	90 h

Modul PAFM0004 Laser Physics	
Module code	PAFM0004
Module title (German)	Laser Physics
Module title (English)	Laser Physics
Person responsible for the module	Prof. Dr. J. Limpert (FSU), Prof. Dr. S. Nolte (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective Module 628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS and exercise 2 SWS
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Introduction to laser physics (stimulated emission, atomic rate equations, laser pumping and population inversion); • Optical beams and laser resonators; • Laser dynamics; • Q-switching; • Mode locking; • Wavelength tuning and single frequency operation; • Laser systems; • Selected industrial and scientific applications.
Intended learning outcomes	<p>The students</p> <p>understand the fundamental equations and concepts of laser theory</p> <p>can explain the working principles of different laser types, including gas, ruby, and diode-pumped solid-state lasers</p> <p>are familiar with key laser applications and their underlying physical principles</p> <p>can analyze and compare laser systems in terms of design, performance, and application areas</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	<ul style="list-style-type: none">• Siegman, Lasers;• W. Koechner, Solid-State Laser Engineering;• W. Demtröder, Laser Spectroscopy;• D. Bäuerle, Laser Processing and Chemistry;• H.-G. Rubahn, Laser Applications in Surface Science and Technology.
Language of instruction	English

Modul PAFM0005 Optical Metrology and Sensing	
Module code	PAFM0005
Module title (German)	Optical Metrology and Sensing
Module title (English)	Optical Metrology and Sensing
Person responsible for the module	Prof. Dr. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 628 M.Sc. Photonics: compulsory module 128 MSc. Physics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Basic principles • Wave optical fundamentals • Sensors • Fringe projection, triangulation • Interferometry and wave front sensing • Holography • Speckle methods and OCT • Phase retrieval • Metrology of aspheres and freeform surfaces • Confocal methods

Intended learning outcomes	The students understand the basic principles and wave optical fundamentals of optical metrology are familiar with key sensor technologies and measurement techniques can apply interferometry, holography, and speckle methods for precise measurements understand phase retrieval and its role in optical metrology can analyze and compare metrology techniques for aspheres, freeform surfaces, and confocal methods
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul PAFMO006 Introduction to Optical Modeling	
Module code	PAFMO006
Module title (German)	Introduction to Optical Modeling
Module title (English)	Introduction to Optical Modeling
Person responsible for the module	Prof. Dr. F. Wyrowski (FSU), apl. Prof. Dr. U. W. Zeitner (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective Module 628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Concepts of ray tracing; Modeling and design of lens systems; Image formation; Physical properties of lenses and lens materials in optical design; Image aberrations and methods to avoid them; Vectorial harmonic fields; Plane waves; Fourier transformation and spectrum of plane waves representation; Concepts of field tracing; Propagation techniques through homogeneous and isotropic media; Numerical properties of propagation techniques.
Intended learning outcomes	The course enables students to solve problems related to the modeling and design of optical elements and systems. In the first part of the lecture we focus on ray-tracing techniques and its application through image formation. Then we combine the concepts with physical optics and obtain field tracing. It enables the propagation of vectorial harmonic fields through optical systems. In practical exercises the students will get an introduction to the use of commercial optics modeling and design software.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Specialization in „Optics”. This module is regularly offered in parallel on-site and online (hybrid).
Recommended reading	<ul style="list-style-type: none">• H. Gross, Handbook of Optical Systems Vol.1: Fundamentals of Technical Optics, Wiley-VCH;• L. Mandel and E. Wolf, Optical Coherence and Quantum Optics;• L. Novotny and B. Hecht, Principles of Nano-Optics.
Language of instruction	English

Modul PAFMO100 Accelerator-based Modern Physics	
Module code	PAFMO100
Module title (German)	Beschleunigerbasierte moderne Physik
Module title (English)	Accelerator-based Modern Physics
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamentals of atomic physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week, Exercise: 1 h per week or seminar: 2 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Basic concepts of particle accelerators, application of accelerators in basic science and medicine, landmark experiments
Intended learning outcomes	Students gain an overview of the various applications of particle accelerators, in particular for basic science and acquire the ability to solve related exercise problems and to prepare a presentation.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester or seminar talk.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc. Physics: required elective module (Specialization in „Optics“ and “Solid State Physics/Material Science”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English (German on request)
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Modul PAFM0101 Active Photonic Devices	
Module code	PAFM0101
Module title (German)	Active Photonic Devices
Module title (English)	Active Photonic Devices
Person responsible for the module	Prof. Dr. M. Schmidt
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	40 h
- Independent studying (incl. preparations for examination)	80 h
Content	Electro-optical modulation; Acousto-optical devices; Magneto-optics and optical isolation; Integrated lasers; Non-Linear devices for light generation;
Intended learning outcomes	Based on this course the students will acquire a comprehensive overview about active photonic devices such as switches or modulators. The course starts by an introduction to the most important parameters and physical principles. The Lecture will then focus onto real-world devices including the areas of electro-optics, waveguides, acousto-optics, magneto-optics and non-linear optics. During this lecture the fundamental principles as well as devices currently employed in photonics will be discussed to provide the students with the ability to solve related problems and to perform research in related fields.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0102 Analytical Instrumentations	
Module code	PAFM0102
Module title (German)	Analytical Instrumentations
Module title (English)	Analytical Instrumentations
Person responsible for the module	Prof. Dr. A. Tünnermann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Atomic and molecular structure, Basics of atomic spectroscopy techniques, Molecular spectroscopy: absorption, emission, vibrational and spectroscopy and microspectroscopy, basics of magnetic resonance spectroscopy, Hardware of spectrometers/ microscopes: light sources, detectors, optics, material point of view, Current applications and relevance in material and life sciences
Intended learning outcomes	In this course, the student will acquire the knowledge and analytical methods to investigate the structure and composition of matter. Basic principles of atomic and molecular structure will be refreshed towards better understanding experimental analysis techniques such as spectrophotometry, ellipsometry, fluorescence, infrared, Raman, etc. spectroscopy or microscopy. The course will focus on technological aspects of the experimental setup in analytical instrumentations. Modern applications of analytical instrumentations in material and life sciences will be discussed. After successful completion, the student will know their capabilities and limitations.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0103 Applied Laser Technology I	
Module code	PAFM0103
Module title (German)	Applied Laser Technology I
Module title (English)	Applied Laser Technology I
Person responsible for the module	Prof. Dr. C. Eggeling, Prof. Dr. R. Heintzmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Overview over laser beam applications as a contactless and remote probe (macroscopic and microscopic, cw and ultrafast, dealing with spectroscopy, metrology, sensing, and multi-dimensional microscopy); Fundamental concepts of related physical and physico-chemical effects; Absorption and emission of light (selection rules); Ultrafast coherent excitation and relaxation (linear and non-linear optical processes); Light reflection and elastic/inelastic scattering.
Intended learning outcomes	The course covers the fundamentals and concepts of the selected laser applications. The students will acquire the knowledge to develop own solutions for challenges in laser applications.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester and/or seminar talk on topic of own choice
Requirements for awarding credit points (type of examination)	Oral examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0104 Applied Laser Technology II	
Module code	PAFM0104
Module title (German)	Applied Laser Technology II
Module title (English)	Applied Laser Technology II
Person responsible for the module	Prof. Dr. C. Eggeling, Prof. Dr. R. Heintzmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h (bi-weekly)
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Applied Laser Technology using the laser as a tool, microscopic and macroscopic light-materials-interactions, material preparation and modification (with the exception of classical laser materials' processing)
Intended learning outcomes	In various selected topics out of the broad field of laser applications, the students will acquire the knowledge to solve problems related to laser-material interactions (e.g. atom cooling and optical tweezer), laser induced processes in gases, liquids, and matrices (incl. laser isotope separation), materials' preparation and structuring by ablation, deposition and/or modification.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0106 Atomic Physics at High Field Strengths	
Module code	PAFM0106
Module title (German)	Atomic Physics at High Field Strengths
Module title (English)	Atomic Physics at High Field Strengths
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in atomic physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Strong field effects on the atomic structure • Relativistic and QED effects on the structure of heavy ions • X-ray spectroscopy of high-Z ions • Application in x-ray astronomy • Penetration of charged particles through matter • Particle dynamics in of atoms and ions in strong laser fields • Relativistic ion-atom and ion-electron collisions • Fundamental interaction processes • Scattering, absorption and energy loss • Detection methods • Particle creation

Intended learning outcomes	The Module provides insight into the basic techniques and concepts in physics related to extreme electromagnetic fields. Their relevance to nowadays applications will be discussed in addition. The Module also introduces the basic interaction processes of high-energy photon and particle beams with matter, including recent developments of high intensity radiation sources, such as free electron lasers and modern particle accelerators. Experimental methods and the related theoretical description will be reviewed in great detail.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English (German on request)

Modul PAFM0107 Attosecond Laser Physics	
Module code	PAFM0107
Module title (German)	Attosecond Laser Physics
Module title (English)	Attosecond Laser Physics
Person responsible for the module	Dr. A. Pfeiffer
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Strong-Field Laser Physics PAFM0266 or equivalent
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Coherent electron dynamics in atoms and molecules; Strong field effects and ionization; High harmonic generation and phase matching; Techniques for attosecond pulse generation; Transient absorption; Attosecond quantum optics with few-level quantum models.
Intended learning outcomes	The course gives an introduction into the young research field of attosecond physics. Electron dynamics in atoms and molecules on the attosecond time scale (which is the natural timescale for bound electrons) will be discussed, along with modern techniques for attosecond pulse generation and characterization to enable the students to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0120 Biomedical Imaging - Ionizing Radiation	
Module code	PAFM0120
Module title (German)	Biomedical Imaging - Ionizing Radiation
Module title (English)	Biomedical Imaging - Ionizing Radiation
Person responsible for the module	Prof. Dr. J. R. Reichenbach
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to biomedical and medical imaging systems; Physical principles behind the design of selected imaging systems; Technological aspects of each modality; Spatial and temporal resolution; Importance of each modality concerning physical, biological and clinical applications.
Intended learning outcomes	The course introduces the physical principles, properties and technical concepts of imaging systems as they are applied today in medicine and physics. The focus is laid on the use and application of ionizing radiation, which has always been an important aspect of the application of physics to medicine. Applications and current developments will be presented. After having actively participated the students should demonstrate a critical understanding of the theoretical basis and technologies of these imaging systems and have acquired an appreciation of instrumentation and practical issues with different imaging systems. The course is independent of the course Biomedical Imaging – Non-Ionizing Radiation offered in the 2nd semester and does not require previous participation of that course.
Prerequisites for admission to the module examination	students must have earned points in the exercises and assignments (type and extent will be announced at the beginning of the semester)

Requirements for awarding credit points (type of examination)	Written or oral examination. The selected form of the exam will be announced at the beginning of the semester
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0121 Biomedical Imaging - Non Ionizing Radiation	
Module code	PAFM0121
Module title (German)	Biomedical Imaging - Non Ionizing Radiation
Module title (English)	Biomedical Imaging - Non Ionizing Radiation
Person responsible for the module	Prof. Dr. J. R. Reichenbach
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to imaging systems; Physical principles behind the design of selected biomedical imaging systems, including magnetic resonance imaging, ultrasound imaging; Technological aspects of each modality; Importance of each modality concerning physical, biological and clinical applications.
Intended learning outcomes	The course introduces physical principles, properties and technical concepts of imaging systems as they are applied today in medicine and physics. The focus is laid on the use and application of non-ionizing radiation, as utilized, e.g., with magnetic resonance imaging or ultrasound imaging. Applications and current developments will be presented. After active participation the students should demonstrate a critical understanding of the theoretical basis and technologies of these imaging systems and have acquired an appreciation of instrumentation and practical issues with different imaging systems. The course is independent of the course Biomedical Imaging – Ionizing Radiation offered in the 3rd semester.
Prerequisites for admission to the module examination	Students must have earned points in the exercises and assignments (type and extent will be announced at the beginning of the semester)

Requirements for awarding credit points (type of examination)	Written or oral examination. The selected form of the exam will be announced at the beginning of the semester
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0122 Biophotonics	
Module code	PAFM0122
Module title (German)	Biophotonics
Module title (English)	Biophotonics
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Prof. Dr. Ralf Ehrlich (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>The Module provides a deep introduction into the multitude of possible linear and non-linear light biological matter interaction phenomena and thus in modern techniques and applications of frequency-, spatially-, and time-resolved bio-spectroscopy. The course presents a comprehensive overview over modern spectroscopic and optical imaging techniques inclusive specific theoretical methodologies to analyze the experimental spectroscopic data to resolve problems in life sciences. The biological part introduces to molecular and cellular properties of living organisms. It explains the basic structures and functions of prokaryotic and eukaryotic cells as well as the most important biochemical substance classes and biochemical pathways where they are involved. Furthermore, basics in microbiology, especially in antimicrobial resistant bacteria will be provided and combined with the introduction of diagnostic principles and selected infectious diseases. Examples for molecular and serological assay and test development and basic methods for diagnostics and epidemiology will be discussed. This sets the stage for biophotonic applications by showing several examples of how biophotonics can help to shed light on biologically and clinically relevant processes. The Module spans aspects of the scientific disciplines chemistry, physics, biology and medicine. The Exercises will be partly calculating examples and partly in the form a seminar talks of the students presenting current research publications. Intended learning outcomes: The aim of this course is to present modern methods in spectroscopy, microscopy, molecular biology, microbiology and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonics problems.</p>
Intended learning outcomes	<p>The aim of this course is to present modern methods in spectroscopy, microscopy and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonic problems.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	<ul style="list-style-type: none"> • Paras N. Prasad, Introduction to Biophotonics • Textbooks on laser spectroscopy, e.g. Demtröder; on quantum mechanics, e.g. Atkins and on optics, e.g. Zinith/Zinith • Jerome Mertz: Introduction to Optical Microscopy, Roberts & Company Publishers, 2010 • Selected chapters of Handbook of Biophotonics (Ed. J. Popp) WILEY
Language of instruction	English

Modul PAFM0129 Computational Imaging	
Module code	PAFM0129
Module title (German)	Computational Imaging
Module title (English)	Computational Imaging
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Dr. Lars Lötgering (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and Programming Lab 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>Review: Linear Algebra, Calculus, Python</p> <ul style="list-style-type: none"> • Optimization part 1: Continuous (Euler Lagrange) and Discrete (multivariate calculus) • Programming lab: genetic algorithms + Fermat principle • Optimization part 2: nonlinear optimization, regularization, Lagrange multipliers • Optimization part 3: Convex techniques, l1 minimization • Programming lab: single pixel camera • Optimization part 4: Automatic differentiation • Matrix representation of coherent optical systems Programming lab: keras toolbox, optical eigenmodes • Multiple scattering: Born / Rytov series, beam propagation method • Tomographic inversion • Programming lab: Foldy-Lax scattering theory • Phase retrieval part 1: coherent diffraction imaging (CDI) • Phase retrieval part 2: ptychography • Programming lab: hybrid input output, shrink wrap, ptychography • Phase retrieval part 3: Fourier ptychography • Image deconvolution: structured illumination microscopy, pupil engineering • Programming lab: extended depth-of-field systems • Imaging with spatially partially coherent light • Parameter estimation: Fisher information and Cramer Rao lower bound • Programming lab: Coded aperture imaging, resolution assessment, edge responses, modulation transfer function, Fourier ring correlation • Neural networks part 1: Image classification • Neural networks part 2: Image regression • Programming lab: digit recognition, counting red blood cells
Intended learning outcomes	Understanding the interplay between forward and inverse modeling in optical systems. Hands-on programming skills.
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Language of instruction	English

Modul PAFM0130 Computational Photonics	
Module code	PAFM0130
Module title (German)	Computational Photonics
Module title (English)	Computational Photonics
Person responsible for the module	Prof. Dr. T. Pertsch (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge of a computer programming language and computational physics will be helpful.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to the problem – Maxwell's equations and the wave equation; Free space propagation techniques; Beam propagation methods applied to problems in integrated optics; Mode expansion techniques applied to stratified media; Mode expansion techniques applied to spherical and cylindrical objects; Multiple multipole technique; Boundary integral method; Finite-Difference Time-Domain method; Finite Element Method; Computation of the dispersion relation (band structure) of periodic media; Mode expansion techniques applied to gratings; Other grating techniques; Contemporary problems in computational photonics.
Intended learning outcomes	The course aims at an introduction to various techniques used for computer based optical simulation. Therefore, the student should learn how to solve Maxwell's equations in homogenous and inhomogeneous media rigorously as well as on different levels of approximation. The course concentrates predominantly on teaching numerical techniques that are useful in the field of micro- and nanooptics.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Taflove and S.C. Hagness, Computational Electrodynamics
Language of instruction	English

Modul PAFM0131 Fundamental Atomic and Nuclear Processes in Highly Ionized Matter	
Module code	PAFM0131
Module title (German)	Fundamental Atomic and Nuclear Processes in Highly Ionized Matter
Module title (English)	Fundamental Atomic and Nuclear Processes in Highly Ionized Matter
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in atomic and nuclear physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Lecture 1: "X-ray spectroscopy of hot plasmas" basic properties of atomic systems (level structure, transition rates, etc.) atomic charge-exchange processes in plasmas, charge state distributions creation of plasmas: facilities for stored and trapped ions x-ray detectors and techniques for spectroscopy and polarimetry x-ray diagnosis of plasmas in the laboratory and nature Lecture 2: "Nuclear matter and the formation of elements" Properties of nuclear matter Stability of the atomic nucleus Nuclear models and masses of atomic nuclei Nuclear processes related to the creation of the elements Nuclear radiation and radiation detectors Experimental techniques
Intended learning outcomes	The students will gain an overview of experiments addressing astrophysical topics, in particular concerning ionized matter and will be enabled to solve respective problems.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	The above mentioned lectures are offered alternately. 128 M.Sc. Physics: Required elective module (Specialization in „Optics“ and “Solid State Physics/Material Science”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English (German on request)

Modul PAFM0132 Optical system design fundamentals	
Module code	PAFM0132
Module title (German)	Optical system design fundamentals
Module title (English)	Optical system design fundamentals
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Basic technical optics; • Paraxial optics; • Imaging systems; • Aberrations; • Performance evaluation of optical systems; • Correction of optical systems; • Optical system classification; • Special system considerations.
Intended learning outcomes	This course covers the fundamental principles of classical optical system design, the performance assessment and the correction of aberrations. In combination of geometrical optics and physical theory the students will learn the basics to understand optical systems, which can be important for experimental work and enable them to solve related problems.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0150 Renewable Energies	
Module code	PAFM0150
Module title (German)	Erneuerbare Energien
Module title (English)	Renewable Energies
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 128 LA Regelschule Physik: Required elective module 128 LA Gymnasium Physik: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Basics of energy supply in Germany; Potential of renewable energies; Principles of the energy balance of planets; Thermodynamics of the atmosphere; Physics of wind energy systems; Elements of solar power generation.
Intended learning outcomes	After acquiring of knowledge on the fundamentals of renewable energies the students will develop the skills for the independent evaluation of different types of renewable energies.
Prerequisites for admission to the module examination	Details will be defined at the beginning of the semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English or German (depending on audience)

Modul PAFM0151 Experimental Nonlinear Optics	
Module code	PAFM0151
Module title (German)	Experimental Nonlinear Optics
Module title (English)	Experimental Nonlinear Optics
Person responsible for the module	Prof. Dr. G. G. Paulus (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Propagation of light in crystals; • Properties of the non-linear susceptibility tensor; • Description of light propagation in non-linear media; • Parametric effects; • Second harmonic generation; • Phase-matching; • Propagation of ultrashort pulses; • High-harmonic generation; • Solitons

Intended learning outcomes	The students understand light propagation in nonlinear media and the role of the nonlinear susceptibility tensor can describe and analyze parametric effects and second harmonic generation grasp the concept of phase-matching and its importance in nonlinear optical processes are familiar with ultrashort pulse propagation and high-harmonic generation can explain soliton formation and its relevance in nonlinear optics
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“)
Recommended reading	
Language of instruction	English

Modul PAFM0160 Fiber Optics	
Module code	PAFM0160
Module title (German)	Fiber Optics
Module title (English)	Fiber Optics
Person responsible for the module	Prof. Dr. M. Schmidt (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Properties of optical fibers; • Light propagation in optical fibers; • Technology and characterization techniques; • Special fiber types (photonic crystal fibers, hollow fibers, polarization maintaining fibers); • Fiber devices (e.g. fiber amplifiers and lasers); • Applications
Intended learning outcomes	<p>Students</p> <p>understand the fundamental properties and light propagation in optical fibers</p> <p>are familiar with fiber fabrication, characterization techniques, and special fiber types</p> <p>can analyze fiber-based devices such as amplifiers and lasers</p> <p>understand key applications of optical fibers in communication, sensing, and laser technology</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	Snyder/Love, Optical Waveguide Theory; Okamoto, Fundamentals of Optical Waveguides.
Language of instruction	English

Modul PAFM0165 Fundamentals of Laser Physics	
Module code	PAFM0165
Module title (German)	Grundlagen der Laserphysik
Module title (English)	Fundamentals of Laser Physics
Person responsible for the module	Prof. Dr. J. Limpert, Dr. J. Rothhardt
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Modules Quantum Theory and Atoms and Molecules or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics“
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	6 CP
Work load:	180 h
- In-class studying	60 h
- Independent studying	120 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • laser principle and essential laser types; • Pumping concepts and optical amplification; • Stable and unstable resonators; • single frequency lasers; • ultrafast lasers; • essential laser types and their characteristics.
Intended learning outcomes	<ul style="list-style-type: none"> • Fundamentals of absorption and emission; • inversion / optical amplification; • concepts for generating coherent light; • Laser principle; • Basic principles of non-linear optics.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	<ul style="list-style-type: none">• Optik, Licht und Laser, D. Meschede;• Lasers, T. Siegman;• Laser, F. K. Kneubühl;• Laser – Grundlagen, Systeme, Anwendungen, J. und H.-J. Eichler, Springer;• Laser Spectroscopy, W. Demtröder.
Language of instruction	German

Modul PAFM0170 High-Intensity/Relativistic Optics	
Module code	PAFM0170
Module title (German)	High-Intensity/Relativistic Optics
Module title (English)	High-Intensity/Relativistic Optics
Person responsible for the module	Prof. Dr. M. Kaluza (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • High-intensity laser technology; • Laser plasma physics; • Laser accelerated particles and applications.
Intended learning outcomes	<p>The students understand the principles of high-intensity laser technology and its key components are familiar with laser-plasma interactions and their physical foundations</p> <p>can analyze laser-driven particle acceleration and its applications in science and technology</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none">• W. L. Kruer, The Physics of Laser Plasma Interactions, Westview press (2003), Boulder Colorado;• P. Gibbon, Short Pulse Laser Interactions with Matter, Imperial College Press (2005), London;• F. F. Chen, Introduction to Plasma Physics and Controlled Fusion, Vol. 1: Plasma Physics, Springer (1984).
Language of instruction	English

Modul PAFM0171 Milestones in Optics	
Module code	PAFM0171
Module title (German)	Milestones in Optics
Module title (English)	Milestones in Optics
Person responsible for the module	Prof. Dr. C. Spielmann, Dr. C. Forstner
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Seminar: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	The seminar covers the history of optics from the antiquity to the 20th century: Starting with Greek theories of vision and ending with quantum optics. A strong focus will be given on the development of concepts and experiments that influenced today's thinking about light and optics, such as wave particle dualism or the Abbe diffraction limit. An excursion to the Jena's Optical Museum is part of the seminar.
Intended learning outcomes	In close collaboration with the supervisor, the student will work on an independent project. The students will develop the ability to evaluate critically the arguments and analytical methods of historians. They will learn developing their own interpretations based on critical assessments of primary source evidence and independent research.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Scientific Talk (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul PAFM0180 Image Processing	
Module code	PAFM0180
Module title (German)	Image Processing
Module title (English)	Image Processing
Person responsible for the module	Prof. Dr. Joachim Denzler (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Digital image fundamentals (Image Sensing and Acquisition, Image Sampling and Quantization) • Image Enhancement in the Spatial Domain (Basic Gray Level Transformations, Histogram Processing, Spatial Filtering) • Image Enhancement in the Frequency Domain (Introduction to the Fourier-Transform and the Frequency Domain, Frequency Domain Filtering, Homomorphic Filtering) • Image Restoration (Noise Models, Inverse Filtering, Geometric Distortion) • Color Image Processing Image Segmentation (Detection of Discontinuities, Edge Linking and Boundary Detection, Thresholding, Region-Based Segmentation) • Representation and Description Applications

Intended learning outcomes	The course covers the fundamentals of digital image processing. Based on this the students should be able to identify standard problems in image processing to develop individual solutions for given problems and to implement image processing algorithms for use in the experimental fields of modern optics.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Gonzalez, Woods, Digital Image Processing, Prentice Hall, 2001
Language of instruction	English

Modul PAFM0181 Image Processing in Microscopy	
Module code	PAFM0181
Module title (German)	Image Processing in Microscopy
Module title (English)	Image Processing in Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	All the image processing and simulations will be practiced in exercises using MatLab and the free image processing toolbox DIPImage (www.diplib.org). The student needs to be familiar with MatLab at a basic level and with basic concepts of image processing such as filtering and thresholding. The Image Processing lecture by Prof. Denzler in the second term forms a good basis for this course.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	We will show different methodologies to extract specific information such as for example the average speed of diffusing particles or the locations and areas of cells from the multidimensional image data. Also fitting quantitative models to extracted data will be treated. Simulation of far-field intensity distribution by using simple Fourier-space based approaches is treated with and without considering the vectorial nature of the oscillating electro-magnetic field.

Intended learning outcomes	Current microscopy often acquires a large amount of image data from which the biological or clinical researcher often needs to answer very specific questions. A major topic is the reconstruction of the sample from the acquired, often complex, microscopy data. To solve such inverse problems, a good model of the data acquisition process is required, ranging from assumptions about the sample (e.g. a positive concentration of molecules per voxel), assumptions about the imaging process (e.g. the existence of an incoherent spatially invariant point spread function) to modeling the noise characteristics of the detection process (e.g. read noise and photon noise).
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul PAFM0182 Advanced Optical Design	
Module code	PAFM0182
Module title (German)	Advanced Optical Design
Module title (English)	Advanced Optical Design
Person responsible for the module	Prof. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in geometrical and physical optics.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Paraxial imaging; • Basics of optical systems; • Eikonal theory; • Geometrical aberrations, representations, expansion; • Detailed discussion of primary aberrations; • Sine condition, isoplanatism, afocal cases; • Wave aberrations and Zernike representation; • Miscellaneous aspects of aberration theory.
Intended learning outcomes	This course covers the fundamental principles of classical optical imaging and aberration theory of optical systems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0183 Introduction to Nanooptics	
Module code	PAFM0183
Module title (German)	Introduction to Nanooptics
Module title (English)	Introduction to Nanooptics
Person responsible for the module	Prof. Dr. I. Staude (FSU), Prof. Dr. T. Pertsch (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Surface-plasmon-polaritons; • Plasmonics; • Photonic crystals; • Fabrication and optical characterization of nanostructures; • Photonic nanomaterials / metamaterials / metasurfaces; • Optical nanoemitters; • Optical nanoantennas.

Intended learning outcomes	The course provides an introduction to the broad research field of nanooptics. The students will learn about different concepts which are applied to control the emission, propagation, and absorption of light at subwavelength spatial dimensions. Furthermore, they will learn how nanostructures can be used to optically interact selectively with nanoscale matter, a capability not achievable with standard diffraction limited microscopy. After successful completion of the course the students should be capable of understanding present problems of the research field and should be able to solve basic problems using advanced literature.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	L. Novotny and B. Hecht, Principles of Nano-Optics, Cambridge 2006; P. Prasad, Nanophotonics, Wiley 2004; J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Photonic Crystals – Molding the Flow of Light, Princeton University Press (2008) list of selected journal publications given during the lecture.
Language of instruction	English

Modul PAFM0184 Integrated Optics	
Module code	PAFM0184
Module title (German)	Integrated Optics
Module title (English)	Integrated Optics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The lecture will cover a significant part of integrated quantum photonics, which is one of the pillars of the current quantum technology development. In particular, the lecture will cover the following topics <ul style="list-style-type: none"> • Integrated optics on a single photon level • Generation and manipulation of quantum states of light using integrated waveguides • Overview over integrated photonic platforms and fabrication of passive and active waveguide structures • Quantum walks in linear and non-linear waveguide lattices • Introduction to photonic quantum computation and simulation • Measurements using superconducting nanowire single photon detectors and transition edge sensors

Intended learning outcomes	<p>The course should provide the participating students with a profound knowledge on the state of the art of integrated optics used for the realization of quantum optical devices.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of integrated quantum photonics and will be able to develop own concepts for integrated quantum circuitry.</p> <p>The intended learning outcome is that the students are introduced to the basics on the field of integrated quantum optics and its applications. Therefore, course starts with an overview on the generation of non-classical states of light with special attention on integrated solutions. Afterwards several integrated photonic platforms will be discussed ranging from fabrication to performance and useability.</p> <p>Based on that the on-chip manipulation of non-classical states of light will be discussed. This starts with the very general concept of quantum walks and continues towards quantum simulation. It ends with an introductory to photonic quantum computing with a clear focus on practical implementation of quantum photonic gate structures.</p> <p>The course closes with the discussion on non-classical light detection in integrated photonics.</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0185 Innovation Methods in Photonics	
Module code	PAFM0185
Module title (German)	Innovation Methods in Photonics
Module title (English)	Innovation Methods in Photonics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Rapid prototyping technologies in photonics • Innovation management and design thinking • Hands-on/practical examples of photonics prototyping • Entrepreneurial skills and business modelling • Basics of intellectual property rights

Intended learning outcomes	<p>The students will learn how the results of their scientific research can be turned into relevant innovations as an important part of their future career. On the one hand, the course will enable students to understand and to drive innovation processes in photonics companies. On the other hand, students will develop an entrepreneurial skill set for the independent economical exploitation of scientific ideas.</p> <p>Therefore, the course introduces the basic knowledge on innovation management, entrepreneurship, and intellectual property rights. To practice their skills, the students will also conduct their own photonics innovation project during the semester by working hands-on in small teams in the photonics makerspace Lichtwerkstatt. During this practical part, they acquire and apply a thorough knowledge of photonic rapid prototyping technologies (e.g. 3d- scanning and printing, laser cutting, microcontrollers, ...) and the most important creativity methods and project management skills. To cover this range of topics, the course will be supported by guest lecturers from different sectors (academia, industry).</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0187 Ion traps and precision experiments	
Module code	PAFM0187
Module title (German)	Ionenfallen und Präzisionsexperimente
Module title (English)	Ion traps and precision experiments
Person responsible for the module	Jun.-Prof. Dr. P. Mücke
Recommended or expected prior knowledge	Basics in electrodynamics, quantum mechanics, and atomic physics
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics specialization "Optics": Required elective module 128 LA Gymnasium Physik: Required elective module 528 M.Sc. Quantum Science and Technology: Required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Basics of ion trap physics; Paul and Penning traps; Cooling techniques, in particular laser cooling methods; Coherent manipulation of electronic and motional states; detection techniques; Application of ion traps for precision experiments: optical clocks, quantum logic spectroscopy, ion traps as a platform for quantum computing, high-resolution mass spectrometry, measurements of g-factors and magnetic moments
Intended learning outcomes	Understanding the concepts of Paul and Penning traps as well as the applied techniques; knowledge of the discussed precision experiments; ability to deepen knowledge independently through latest scientific literature
Prerequisites for admission to the module examination	50% of the points of the exercise sheets; active participation in the exercises by presenting own solutions and discussing content
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Recommended reading	An up-to-date literature list will be announced at the beginning of the semester.
Language of instruction	English

Modul PAFMO200 Laser Driven Radiation Sources	
Module code	PAFMO200
Module title (German)	Laser Driven Radiation Sources
Module title (English)	Laser Driven Radiation Sources
Person responsible for the module	Prof. Dr. M. Zepf
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in plasma physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Laser Plasma Interactions • Principles of Plasma Accelerators • Ultrafast Photon Sources • Scattering of photons from particle beams
Intended learning outcomes	The course introduces the basic interaction processes of high-energy lasers with plasmas and particle beams with a particular emphasis on the extremely intense sources of proton, electron and photons with pulse durations in the femtosecond regime. Students will be enabled to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	presentation and/or oral examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English/German depending on participants

Modul PAFM0201 Laser Engineering	
Module code	PAFM0201
Module title (German)	Laser Engineering
Module title (English)	Laser Engineering
Person responsible for the module	Prof. Dr. M. Kaluza
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Prior knowledge in laser physics is strongly recommended.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • origin and dependencies of absorption and emission cross sections • Ytterbium based laser media • design of laser diode pump engines, • special topics in geometrical optics for amplifier design • basic calculations for layout of diode pumped high energy amplifiers • Ytterbium based laser materials and cryogenic cooling • limitations and special topics (laser induced damage threshold (LIDT), amplified spontaneous emission (ASE) ...)
Intended learning outcomes	This is an application-oriented course focusing on topics needed for development and design of diode pumped high energy class laser systems. Besides general topics the main part of this lecture is dedicated to ytterbium-based laser systems. Besides basic knowledge like the spectral properties of laser materials and their significance for a laser system, further key topics like laser induced damage thresholds, laser diode pump engines, modeling of amplification and amplified spontaneous emission will be discussed. Students will be enabled to solve related problems.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMO203 Lens Design I	
Module code	PAFMO203
Module title (German)	Lens Design I
Module title (English)	Lens Design I
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Introduction and user interface; • Description and properties of optical systems; • Geometrical and wave optical aberrations; • Optimization; • Imaging simulation; • Introduction into illumination systems; • Correction of simple systems; • More advanced handling and correction methods.
Intended learning outcomes	This course gives an introduction in layout, performance analysis and optimization of optical systems with the software Zemax and enables the students to solve problems of optical system design.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0204 Lens Design II	
Module code	PAFM0204
Module title (German)	Lens Design II
Module title (English)	Lens Design II
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in aberration theory and optical design as acquired in the course on "Lens Design I".
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Paraxial imaging and basic properties of optical systems; • Initial systems and structural modifications; • Chromatical correction; • Aspheres and freeform surfaces; • Optimization strategy and constraints; • Special correction features and methods; • Tolerancing and adjustment.
Intended learning outcomes	This course covers the advanced principles of the development of optical systems and enables the students to solve advanced problems of optical system design.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMO205 Light Microscopy	
Module code	PAFMO205
Module title (German)	Light Microscopy
Module title (English)	Light Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>Starting from geometrical optics the imaging system will be described and optical aberrations will be discussed. Moving on to wave optics monochromatic waves will be taken as the basis for the description of coherent imaging. Combined with scattering theory in the 1st Born approximation a fundamental understanding of the possibilities and limitations in imaging is gained. The concept of the amplitude transfer function and McCutchens 3-dimensional pupil function are introduced. On this basis various coherent imaging modes are discussed including holographic approaches and their limitations, and optical coherent tomography.</p> <p>The working principles of light-detectors are discussed and the requirements for appropriate sampling of images.</p> <p>Finally various modes of fluorescence microscopy and high-resolution microscopy will be covered.</p> <p>The exercises will be calculating examples, also involving hands-on computer based modeling using Matlab and other tools.</p>

Intended learning outcomes	The students understand imaging principles, including optical aberrations and coherent imaging can describe key concepts like the amplitude transfer function and 3D pupil function are familiar with holography, optical coherence tomography, and fluorescence microscopy understand light detectors and image sampling requirements can apply computational tools for modeling optical imaging systems
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMO210 Machine Learning for Quantum Science	
Module code	PAFMO210
Module title (German)	Machine Learning for Quantum Science
Module title (English)	Machine Learning for Quantum Science
Person responsible for the module	Dr. X. Gu
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology: required elective module 128 M.Sc. Physics focus "Optics": required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<p>Artificial intelligence has become as a powerful tool in quantum science, enabling researchers to simulate complex systems, optimize experimental procedures, and discover new ideas and experiments. This course introduces the principles and practice of applying artificial intelligence (AI) and machine learning (ML) techniques to quantum physics, providing students with both theoretical foundations and hands-on computational skills. Topics include:</p> <ul style="list-style-type: none"> • Basic AI/ML techniques for physicists • Differentiable programming • Generative models and reinforcement learning • Quantum circuit optimization and design • Quantum parameter estimation and measurement strategies • Quantum experiments design and discovery • Interpretable AI in quantum physics

Intended learning outcomes	<p>This course introduces and deepens students' understanding of artificial intelligence techniques applied to quantum information science. By actively participating in this course, students will:</p> <ul style="list-style-type: none"> • Develop both theoretical understanding and practical skills at the intersection of quantum science and artificial intelligence. • Understand how artificial intelligence and machine learning can address challenges in quantum physics, such as quantum state estimation and experimental design. • Gain hands-on experience implementing AI/ML methods in Python (using frameworks like PyTorch and JAX). • Engage with current research literature to identify open questions and design AI systems for quantum tasks.
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	<p>Students are encouraged to explore the following papers relevant to the course topics:</p> <ul style="list-style-type: none"> • Krenn, M. et al., Computer-inspired quantum experiments. Nat Rev Phys 2, 649–661 (2020) • Krenn, M. et al., Artificial intelligence and machine learning for quantum technologies, Phys. Rev. A 107, 010101 (2023) • Dawid, A. et al., Modern applications of machine learning in quantum sciences, arXiv:2204.04198 (2022) • Acampora, G. et al., Quantum computing and artificial intelligence: status and perspectives, arXiv:2505.23860 (2025) <p>A more detailed and regularly updated list of supplementary literature and resources will be provided at the beginning of the semester and throughout the course.</p>
Language of instruction	English

Modul PAFM0220 Micro/Nanotechnology	
Module code	PAFM0220
Module title (German)	Micro/Nanotechnology
Module title (English)	Micro/Nanotechnology
Person responsible for the module	Apl. Prof. Uwe Zeitner (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • demands of micro- and nano-optics on fabrication technology • basic optical effects of micro- and nano-structures and their description • typical structure geometries in micro- and nano-optics • coating technologies • lithography (photo-, laser-, electron-beam) and its basic physical principles • sputtering and dry etching • special technologies (melting, reflow, ...) • applications and examples

Intended learning outcomes	In this course the student will learn about the fundamental fabrication technologies which are used in microoptics and nanooptics. This includes an overview of the physical principles of the different lithography techniques, thin film coating and etching technologies. After successful completion of the course the students should have a good overview and understanding of the common technologies used for the fabrication of optical micro- and nano-structures. They know their capabilities and limitations.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul PAFM0221 Microscopy	
Module code	PAFM0221
Module title (German)	Microscopy
Module title (English)	Microscopy
Person responsible for the module	Prof. Dr. R. Heintzmann (FSU), Prof. Dr. C. Eggeling (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Optical microscopy • Circumventing the resolution limit • Electron microscopy • Atomic force microscopy
Intended learning outcomes	This Module provides an introduction into the fundamentals of modern light and electron microscopy and enables the students to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0222 Modern Methods of Spectroscopy	
Module code	PAFM0222
Module title (German)	Moderne Methoden der Spektroskopie
Module title (English)	Modern Methods of Spectroscopy
Person responsible for the module	Prof. Dr. C. Spielmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Fundamentals of light-matter interaction; • Experimental tools of spectroscopy; • laser spectroscopy; • Time-resolved spectroscopy; • Laser cooling; • THz and X-ray spectroscopy; • photoelectron spectroscopy; • Applications of laser spectroscopy in physics, chemistry, medicine.
Intended learning outcomes	Understanding the methods of spectroscopy based on new developments in optics; impart knowledge about the design of a spectroscopic experiment; Ability to independently solve spectroscopic questions.
Prerequisites for admission to the module examination	
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul PAFMO230 Nano Engineering	
Module code	PAFMO230
Module title (German)	Nano Engineering
Module title (English)	Nano Engineering
Person responsible for the module	Dr. S. Höppener, Prof. Dr. U. S. Schubert
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Building with Molecules • Self-organization and self-assembled coatings • Chemically sensitive characterization methods • Nanomaterials for optical applications • Nanowires and nanoparticles • Nanomaterials in optoelectronics • Bottom-up synthesis strategies and nanolithography • Polymers and self-healing coatings • Molecular motors • Controlled polymerization techniques

Intended learning outcomes	<p>A large diversity of nanomaterials can be efficiently produced by utilizing chemical synthesis strategies. The wide range of nanomaterials, i.e., nanoparticles, nanotubes, micelles, vesicles, nanostructured phase separated surface layers etc. opens on the one hand versatile possibilities to build functional systems, on the other hand also the large variety of techniques and processes to fabricate such systems is also difficult to overlook.</p> <p>Traditionally the communication in the interdisciplinary field of nanotechnology is difficult, as expertise from different research areas is combined. This course aims on the creation of a common basic level for communication and knowledge of researchers of different research fields and to highlight interdisciplinary approaches which lead to new fabrication strategies. The course includes basic chemical synthesis strategies, molecular self-assembly processes, chemical surface structuring, nanofabrication and surface chemistry to create a pool of knowledge to be able to use molecular building blocks in future research projects.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0231 Nonlinear Dynamics in Optical Systems	
Module code	PAFM0231
Module title (German)	Nonlinear Dynamics in Optical Systems
Module title (English)	Nonlinear Dynamics in Optical Systems
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in electrodynamics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Non-Linear dynamics in optical fibers and waveguides • Solution of non-linear partial differential equations • Solitons and collapse in optical systems • Super continuum generation
Intended learning outcomes	Understanding the theoretical fundamentals of non-linear dynamics in optical systems the students are enabled to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Examination mark (100%) The mark is composed by an Exercise mark (25%) and an oral examination (75%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	German or English on request
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Modul PAFM0233 Neuromorphic Photonics - Platforms & Applications	
Module code	PAFM0233
Module title (German)	Neuromorphe Photonik - Plattformen und Anwendung
Module title (English)	Neuromorphic Photonics - Platforms & Applications
Person responsible for the module	Dr. Elena Goi and Prof. Thomas Pertsch
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	attendance of "Fundamentals of Modern Optics" module or equivalent
Type of module (compulsory module, required elective module, elective module)	128 MSc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> • Notions of brain physiology. • Introduction to AI, machine learning, neuromorphic computing and analog computing. • Comprehensive overview of neuromorphic photonics field background and historical development. • Review of the recent developments in photonic neuromorphic models, photonic platforms and accelerators for neuromorphic computing. • Discuss fields and applications that can leverage on these new platforms. • Analyze the current challenges faced in advancing the field and the emerging directions in neuromorphic photonic and AI applied to photonic problems, such as AI photonic chips, quantum neural networks, 3D optical neural networks etc.. • The tutorials will focus on design and training of diffractive neural networks and photonic integrated neural network.

Intended learning outcomes	<ul style="list-style-type: none"> • Fundamentals of neurological structures and neuromorphic models in machine learning and deep learning. • Knowledge of the historical and most recent developments of the neuromorphic photonics field. • Understanding of the applications of neuromorphic photonic technologies and the emerging directions in the field. • Practical implementation of diffractive neural network design and training. • Practical implementation of integrated photonic neural networks with cascades of Mach-Zehnder interferometers. • Capacity to analyze scientific articles, expand understanding through contemporary research, and effectively present project work.
Prerequisites for admission to the module examination	None
Requirements for awarding credit points (type of examination)	Project team report (50%), oral examination (50%)
Additional information on the module	<ul style="list-style-type: none"> • Neuromorphic Photonic Devices and Applications, Edited by Min Gu et al., 2024, SPIE – Elsevier • Neuromorphic Photonics, Edited by P. R. Prucnal and B. J. Shastri, 2017, CRC Press • Modern Optics: Edition 2. B. D. Guenther, Oct 2015, OUP Oxford <p>The suggested key literature list will be provided at the beginning of each lecture.</p>
Recommended reading	<ul style="list-style-type: none"> • Neuromorphic Photonic Devices and Applications, Edited by Min Gu et al., 2024, SPIE – Elsevier • Neuromorphic Photonics, Edited by P. R. Prucnal and B. J. Shastri, 2017, CRC Press • Modern Optics: Edition 2. B. D. Guenther, Oct 2015, OUP Oxford <p>The suggested key literature list will be provided at the beginning of each lecture.</p>
Language of instruction	English

Modul PAFM0240 Optical Engineering	
Module code	PAFM0240
Module title (German)	Optical Engineering
Module title (English)	Optical Engineering
Person responsible for the module	Prof. Dr. C. Franke
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	30 h
- Independent studying	90 h
(incl. preparations for examination)	

Modul PAFM0242 Optics for Spectroscopists: Optical Waves in Solids	
Module code	PAFM0242
Module title (German)	Optics for Spectroscopists: Optical Waves in Solids
Module title (English)	Optics for Spectroscopists: Optical Waves in Solids
Person responsible for the module	Dr. habil. T. Mayerhöfer
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	30 h
- Independent studying	90 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> • Limitations and non-linearities of the (Bouguer-)Beer-Lambert law derived from wave-optics based approaches. • Reflection and Refraction at isotropic and anisotropic interfaces (Yeh's formalism, Berreman formalism, special cases, Euler orientation representations, example spectra etc.) • Dispersion relations in isotropic and anisotropic media (Lorentz-model, Lorentz-profile, coupled oscillator model, semi-empirical 4-Parameter model, inverse dielectric function modelling, Kramers-Kronig relations etc.) • Spectral analysis of media and layered systems down to triclinic symmetry and, ultimately, without prior knowledge of orientation; consequences for randomly-oriented or partly-oriented systems.
Intended learning outcomes	The students will acquire an understanding about how pre-Maxwell spectroscopic concepts and quantities like the Beer-Lambert law, linear dichroism and absorbance are properly modified by their wave-optics based analogues. The final goal is to be able to quantitatively understand and analyze spectral patterns based on dispersion theory and matrix formalisms for media of arbitrary symmetry and orientation.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0250 Particles in Strong Electromagnetic Fields	
Module code	PAFM0250
Module title (German)	Particles in Strong Electromagnetic Fields
Module title (English)	Particles in Strong Electromagnetic Fields
Person responsible for the module	Prof. Dr. M. Zepf
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on quantum mechanics und special relativity
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Electrons in constant fields • Electrons in electromagnetic pulses • Radiation produced by particles in extreme motion • Radiation reaction • QED effects in strong laser fields
Intended learning outcomes	This course is devoted to the dynamics of charged particles in electromagnetic fields. Starting with motion of electrons in constant magnetic and electric fields, the course continues with the electron motion in electromagnetic pulses (i.e. laser pulses) of high strength (i.e. when laser pressure becomes dominant). Radiation produced by electrons in extreme motion will be calculated for several most important cases: synchrotron radiation, Thomson scattering, undulator radiation. Effects of radiation reaction on electron motion will be discussed. The last part of the course will briefly discuss the QED effects in strong laser fields: stochasticity in radiation reaction, pair production by focused laser pulses and QED cascades. Analytical framework will be complemented with the help of numerical calculations.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Presentation or oral Exam (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0253 Physics of Free-Electron Laser	
Module code	PAFM0253
Module title (German)	Physics of Free-Electron Laser
Module title (English)	Physics of Free-Electron Laser
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • physical foundations of X-ray lasers • undulators • FEL differential equation • Instrumentation • selected applications
Intended learning outcomes	<p>The student understands the physical foundations, instrumentation, and selected applications of FELs.</p> <p>Acquisition of the competence to judge the applicability and significance of FELs to address problems in X-ray physics.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%).
Additional information on the module	<p>128 M.Sc. Physics: Required elective module (Specialization in „Optics“)</p> <p>If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).</p>

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0254 Physics of Ultrafast Optical Discharge and Filamentation	
Module code	PAFM0254
Module title (German)	Physics of Ultrafast Optical Discharge and Filamentation
Module title (English)	Physics of Ultrafast Optical Discharge and Filamentation
Person responsible for the module	Prof. Dr. C. Spielmann, Dr. D. Kartashov
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • physics of photoionization • optical breakdown • basics of plasma kinetics • LIBS Laser induced breakdown spectroscopy • physics of filamentation • applications: LIDAR, lightning discharge, supercontinuum generation
Intended learning outcomes	In a selected number of topics out of the broad field of high power laser matter interactions the students should acquire knowledge of ionization, plasma kinetics, filamentation and applications in spectroscopy metrology and atmospheric science.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0255 Plasma Physics	
Module code	PAFM0255
Module title (German)	Plasma Physics
Module title (English)	Plasma Physics
Person responsible for the module	Prof. Dr. M. Kaluza
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on laser physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> • Fundamentals of plasma physics; • Single particle and fluid description of plasmas; • Waves in plasmas; • Interaction of electromagnetic radiation with plasmas; • Plasma instabilities; • Non-linear effects (shock waves, parametric instabilities, ponderomotive effects, ...).
Intended learning outcomes	This course offers an introduction to the fundamental effects and processes relevant for the physics of ionized matter. After actively participating in this course, the students will be familiar with the fundamental physical concepts of plasma physics, especially concerning astrophysical phenomena but also with questions concerning the energy production based on nuclear fusion in magnetically or inertially confined plasmas.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0256 Physics of Photovoltaics	
Module code	PAFM0256
Module title (German)	Photovoltaik
Module title (English)	Physics of Photovoltaics
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Pertinent elements of thermodynamics and statistical mechanics (diffusion, Boltzmann factor, free energy) • Fundamental concepts of solid state physics • Semiconductors and pn-junction • Diode equation • Shockley-Queisser limit • Design criteria for solar cells
Intended learning outcomes	<ul style="list-style-type: none"> • Profound understanding of the physics underlying the performance of solar cells • Development of an understanding of the role of photovoltaics for covering the energy demand of modern societies. • Capability to solve complex problems pertinent to solar cells
Prerequisites for admission to the module examination	Processing of exercise sheets (kind and extend will be announced at the beginning of the semester)
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“ and "Solid-state Physics") If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMO260 Quantum Optics	
Module code	PAFMO260
Module title (German)	Quantum Optics
Module title (English)	Quantum Optics
Person responsible for the module	Prof. Dr. T. Pertsch (FSU), Dr. F. Setzpfandt (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on quantum theory and theoretical optics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Basic introduction to quantum mechanics; • Quantization of the free electromagnetic field; • Non-classical states of light and their statistics; • Experiments in quantum optics; • Semi-classical and fully quantized light-matter interaction; • Non-Linear optics.
Intended learning outcomes	<p>The course will give a basic introduction into the theoretical description of quantized light and quantized light-matter interaction. The derived formalism is then used to examine the properties of quantized light and to understand a number of peculiar quantum optical effects.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum optics and will be able to apply the derived formalism to other problems.</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Grynberg / Aspect / Fabre "Introduction to Quantum Optics"; Garrison / Chiao "Quantum Optics"; Fox "Quantum Optics – An Introduction"; Loudon "The Quantum Theory of Light"; Bachor / Ralph "A Guide to Experiments in Quantum Optics".
Language of instruction	English

Modul PAFMO261 Quantum Computing	
Module code	PAFMO261
Module title (German)	Quantum Computing
Module title (English)	Quantum Computing
Person responsible for the module	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Basic introduction to algorithms and computing • The Qubit and entanglement thereof • Basics of quantum algorithms • Advanced quantum algorithms • Implementation of QuBits and quantum computers • Hands-on circuits

Intended learning outcomes	<p>After active participation in the course, the students will be familiar with the basic concepts of quantum computation and the implementation of quantum algorithms. They will be able to apply their knowledge in the assessment and creation of quantum algorithms and the development of quantum information systems.</p> <p>The intended learning outcome is to introduce the students to the basic usage of quantum bits for information processing. To provide further insight, the course will expand this concept on multipartite systems and introduce the concept of entanglement.</p> <p>In a further step we shall see how individual quantum operations tie together to create algorithms. Important algorithms, such as the quantum Fourier transformation, the algorithms of Shor and Grover will be discussed. To relate the abstract knowledge on quantum algorithms to practical applications, real-world implementations of quantum computers will be discussed.</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMO262 Quantum Communicaton	
Module code	PAFMO262
Module title (German)	Quantum Communicaton
Module title (English)	Quantum Communicaton
Person responsible for the module	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. A. Tünnermann (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Basic introduction to quantum optics; • Quantum light sources; • Encoding, transmission and detection of information with quantum light; • Quantum communication and cryptography; • Quantum communication networks; • Outlook on Quantum metrology and Quantum imaging;
Intended learning outcomes	<p>Goals: The course will give a basic introduction into the usage of quantum states of light for the exchange of generation of quantum light and schemes that leverage these states for the exchange of information, ranging from fundamental concepts and experiments to state of the art implementations for secure communication networks. The course will also give an outlook to aspects of Quantum metrology and imaging. After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.</p>

Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul PAFM0263 Quantum Imaging and Sensing	
Module code	PAFM0263
Module title (German)	Quantum Imaging and Sensing
Module title (English)	Quantum Imaging and Sensing
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. F. Setzpfandt (FSU), Prof. Dr. A. Tünnermann (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Basic introduction to relevant concepts of quantumoptics • Generation of photon pairs • Fundamentals of two-photon interference • Applications of two-photon interference • Optical quantum metrology • Ghost Imaging • Quantum microscopy
Intended learning outcomes	<p>Goals: The course will give a basic introduction into the usage of quantum light, in particular photon pairs, for imaging and sensing. To this end, many basic concepts and applications will be introduced and discussed. Furthermore, students will learn how to mathematically describe quantum sensing schemes in order to understand and predict their properties.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum imaging and sensing and will be able to apply the derived formalism to similar problems.</p>
Requirements for awarding credit points (type of examination)	<p>Written or oral examination (100%)</p> <p>The form of the exam will be announced at the beginning of the semester</p>
Additional information on the module	

Recommended reading	A list of literature and materials will be provided at the beginning of the semester
Language of instruction	English

Modul PAFM0265 Semiconductor Nanomaterials	
Module code	PAFM0265
Module title (German)	Semiconductor Nanomaterials
Module title (English)	Semiconductor Nanomaterials
Person responsible for the module	Prof. Dr. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> • Review of fundamentals of semiconductors • Optical and optoelectronic properties of semiconductors • Effects of quantum confinement • Photonic effects in semiconductor nanomaterials • Physical implementations of semiconductor nanomaterials, including epitaxial structures, semiconductor quantum dots and quantum wires • Advanced topics of current research, including 2D semiconductors and hybrid nanosystems

Intended learning outcomes	This course aims to convey a fundamental understanding of the physics governing the optical and optoelectronic properties of semiconductor nanomaterials. First, the fundamental optical and optoelectronic properties of bulk semiconductors are reviewed, deepening and extending previously obtained knowledge in condensed matter physics. The students will then learn about the effects of quantum confinement in semiconductor systems in one, two or three spatial dimensions, as well as about photonic effects in nanostructured semiconductors. Finally, several relevant examples of semiconductor nanomaterial systems and their applications in photonics are discussed in detail. After successful completion of the course, the students should be capable of understanding present research directions and of solving basic problems within this field of research.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination at the end of the semester and oral presentation on a current research topic
Additional information on the module	
Recommended reading	P. Y. Yu and M. Cardona, Fundamentals of Semiconductors, Springer 2010 C. F. Klingshirn, Semiconductor Optics, Springer 1995 M. Fox, Quantum Optics – An Introduction, Oxford University Press 2006
Language of instruction	English

Modul PAFM0266 Strong-Field Laser Physics	
Module code	PAFM0266
Module title (German)	Strong-Field Laser Physics
Module title (English)	Strong-Field Laser Physics
Person responsible for the module	Prof. Dr. G. G. Paulus (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • characteristic quantities in attosecond laser physics • characteristic effects (above-threshold generation, high-harmonic generation, non-sequential double ionization) • experimental techniques • theoretical description of strong-field electron dynamics • recollision as a fundamental process in strong-field and attosecond laser physics • generation and measurement of attosecond pulses
Intended learning outcomes	Knowledge of the fundamentals of high-field laser physics and attosecond laser physics based on it. Development of skills for the independent treatment of questions of these fields.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	30 min oral exam

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	Review-Artikel Z. Chang: Fundamentals of Attosecond Optics
Language of instruction	English

Modul PAFM0267 Structured Light and Wavefront Shaping	
Module code	PAFM0267
Module title (German)	Structured Light and Wavefront Shaping
Module title (English)	Structured Light and Wavefront Shaping
Person responsible for the module	Prof. T. Cizmár
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 MSc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>Light can be structured to carry complex patterns in intensity, phase, polarization, time, and even frequency. The ability to "sculpt" light is transforming science and technology, enabling applications from high-resolution microscopy to quantum communication.</p> <p>Devices, such as Spatial Light Modulators and Digital Micromirror Devices, now enable dynamic beam shaping into exotic optical structures. Further, they offer ways to beat optical aberrations of real-life optical systems as well as the scrambling of light by optically complex media, such as diffusers and biological tissues.</p> <p>The prospect can make use of intriguing properties of light such as the orbital angular momentum, opening new horizons in microscopy, optical tweezers, quantum information, and high-capacity data links. Further, a primitive multimode optical fibre can, with the technology, be turned into hair-thin endoscope exploring previously inaccessible locations within the living brain.</p>
Intended learning outcomes	Students will acquire the competence to independently generate, control, and apply structured light in practical contexts. By combining theoretical foundations with live demonstrations and hands-on experiments, they will develop the ability to purposefully use these technologies in research and industry, as well as to critically assess their potential.
Prerequisites for admission to the module examination	none

Requirements for awarding credit points (type of examination)	Presentation (100%)
Recommended reading	<ul style="list-style-type: none">• Rubinsztein-Dunlop, Halina, et al. "Roadmap on structured light." Journal of Optics 19.1 (2016): 013001.• Andrews, David L. Structured light and its applications: An introduction to phase-structured beams and nanoscale optical forces. Academic press, 2011.• Cao, Hui, et al. "Controlling light propagation in multimode fibers for imaging, spectroscopy, and beyond." Advances in Optics and Photonics 15.2 (2023): 524-612.
Language of instruction	English

Modul PAFM0270 Theory of Nonlinear Optics	
Module code	PAFM0270
Module title (German)	Theory of Nonlinear Optics
Module title (English)	Theory of Nonlinear Optics
Person responsible for the module	Prof. Dr. U. Peschel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Types and symmetries of non-linear polarization; • Non-Linear optics in waveguides; • Solutions of non-linear evolution equations; • Temporal and spatial solitons; • Super continuum generation.
Intended learning outcomes	The course provides the theoretical background of non-linear optics and quantum optics.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100 %). Written examination (100 %). The final grade will be determined by the exercise performance (25%)and an oral exam (75%).
Additional information on the module	

Recommended reading	<ul style="list-style-type: none">• Agrawal, Govind P.: Contemporary non-linear optics;• Moloney, Jerome V., Newell Alan C.: Non-Linear Optics ;• Sutherland, Richard Lee: Handbook of non-linear optics.
Language of instruction	English

Modul PAFM0271 Thin Film Optics	
Module code	PAFM0271
Module title (German)	Thin Film Optics
Module title (English)	Thin Film Optics
Person responsible for the module	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Basic dispersion models in Thin Film Optics • Optical properties of material mixtures • Interfaces: Fresnels equations • Multiple internal reflections in layered systems • Optical spectra of single thin films • Wave propagation in stratified media • Matrix formalism • Multilayer systems: Quarterwave-stacks and derived systems • Coatings for ultrashort light pulses • Remarks on coating design
Intended learning outcomes	This course is of use for anyone who needs to learn how optical coatings are used to tailor the optical properties of surfaces. After an introduction about the theoretical fundamentals of optical coatings the student should learn to calculate the optical properties of uncoated and coated surfaces. Based on this, typical design concepts and applications will be presented.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%).
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none">• Born/Wolf: Introduction to optics;• H. A. Macleod, Thin Film Optical Filters, Adam Hilger Ltd. 2001;• R. Willey, Practical Design and Productions of Optical Thin Films, Marcel Dekker Inc. 2003;• N. Kaiser, H. K. Pulker (Eds.), Optical Interference Coatings, Springer Series in Optical Sciences, Vol. 88, 2003;• O. Stenzel, The Physics of Thin Film Optical Spectra. An Introduction, Springer Series in Surface Sciences, Vol. 44, 2005.
Language of instruction	English

Modul PAFMO280 Ultrafast Optics	
Module code	PAFMO280
Module title (German)	Ultrafast Optics
Module title (English)	Ultrafast Optics
Person responsible for the module	Prof. Dr. S. Nolte (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in laser physics.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Introduction to ultrafast optics; • Fundamentals; • Ultrashort pulse generation; • Amplification of ultrashort pulses; • Measurement of ultrashort pulses; • Applications; • Generation of attosecond pulses.
Intended learning outcomes	The aim of this course is to provide a detailed understanding of ultrashort laser pulses, their mathematical description as well as their application. The students will learn how to generate, characterize and use ultrashort laser pulses. Special topics will be covered during the seminars.
Prerequisites for admission to the module examination	Talk
Requirements for awarding credit points (type of examination)	Written examination (100%).

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none">• Weiner, Ultrafast Optics;• Diels/Rudolph, Ultrashort Laser Pulse Phenomena;• Rulliere, Femtosecond laser pulses;• W. Koechner, Solid-state Laser engineering;• A. Siegman, Lasers.
Language of instruction	English

Modul PAFM0281 Ultrafast Fibre Laser: Technology and Applications	
Module code	PAFM0281
Module title (German)	Ultrafast Fibre Laser: Technology and Applications
Module title (English)	Ultrafast Fibre Laser: Technology and Applications
Person responsible for the module	Prof. Dr. Markus Schmidt (FSU), Dr. Maria Chernysheva (FSU)
Recommended or expected prior knowledge	Fiber Optics and Ultrafast Optics
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics”: required elective module 628 MSc Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 SWS Exercises: 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> • Review of fundamentals of ultrafast fibre lasers (mode-locking and Q-switching) • Engineering of fibre laser cavities • Ultrashort pulse characterization (autocorrelation, FROG, dispersive Fourier transformation, etc.) • Extreme phenomena, exploration of new wavelength ranges and other latest technology advancements in ultrafast fibre laser development • Detailed overview of the ultrafast laser applications in industry, sensing, and medicine (diagnostics and treatment)

Intended learning outcomes	<p>The aim of the course is to deliver a comprehensive understanding on applied ultrafast laser technology, provide a comparison of solid-state, semiconductor and fibre systems with the focus on the latter, and introduce their modern industrial applications and various research areas.</p> <p>The course, first, will shortly review the basics of fibre optics, rare-earth ion spectroscopy, materials for saturable absorbers and fast modulation techniques, and a variety of operational regimes. The first part of the course will be summarized in pathways towards expected further advancements in the field, covering new research trends, expansion of operation wavelength and operational modalities along with the comparison to existing ultrafast laser technologies.</p> <p>The second and the largest part of the course will be dedicated to the discussion of the existing and emerging applications of ultrafast fibre lasers, including analysis of the corresponding performance requirements and technological goals for a specific application. Starting with high-power industrial applications for material processing, the course will discuss strategies for a further expansion of the ultrafast fibre laser systems towards a more diverse range of applications. These include diagnostics and treatment in medicine, neuroscience field and especially optogenetics, scientific applications for nuclear physics, sensing, metrology and security applications.</p> <p>As the result, students will receive a detailed overview of the road map of the ultrafast fibre laser technology development with further perspectives to employ the knowledge and prospects in their future careers. This will be strengthened during accompanying seminars on latest reported advancements and exercises with practical examples of laser systems.</p>
Prerequisites for admission to the module examination	Completion of the exercises (exact extend will be announced at the beginning of the module)
Recommended reading	Literature will be announced at the beginning of the semester
Language of instruction	English

Modul PAFMO290 XUV and X-Ray Optics	
Module code	PAFMO290
Module title (German)	XUV and X-Ray Optics
Module title (English)	XUV and X-Ray Optics
Person responsible for the module	Prof. Dr. C. Spielmann (FSU), Dr. D. Kartashov (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Complex refractive index in the XUV and X-ray range; • Refractive and grazing incidence optics; • Zone plate optics; • Thomson and Compton scattering; • X-ray diffraction by crystals and synthetic multilayers; • VUV and X-ray optics for plasma diagnostics; • Time-resolved X-ray diffraction; • EUV lithography • XUV- and X-ray microscopy
Intended learning outcomes	The students understand the complex refractive index in the XUV and X-ray range can analyze refractive, grazing incidence, and zone plate optics are familiar with X-ray diffraction and scattering phenomena understand applications in plasma diagnostics and EUV lithography
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	written or oral exam (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFM0901 Topics of Current Research 1	
Module code	PAFM0901
Module title (German)	Topics of Current Research I
Module title (English)	Topics of Current Research 1
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> Advanced topics of current research in optics and photonics
Intended learning outcomes	<ul style="list-style-type: none"> Introduction into a field of current research as a basis for further study and research in this field; Independent solution of Exercise problems; Ability to acquire further knowledge by independent literature studies.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFM0902 Topics of Current Research 2	
Module code	PAFM0902
Module title (German)	Topics of Current Research II
Module title (English)	Topics of Current Research 2
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> Advanced topics of current research in optics and photonics
Intended learning outcomes	<ul style="list-style-type: none"> Introduction into a field of current research as a basis for further study and research in this field; Independent solution of exercise problems; Ability to acquire further knowledge by independent literature studies.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFM0903 Topics of Current Research 3	
Module code	PAFM0903
Module title (German)	Topics of Current Research III
Module title (English)	Topics of Current Research 3
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> Advanced topics of current research in optics and photonics
Intended learning outcomes	<ul style="list-style-type: none"> Introduction into a field of current research as a basis for further study and research in this field; Independent solution of Exercise problems; Ability to acquire further knowledge by independent literature studies.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFM0904 Topics of Current Research 4	
Module code	PAFM0904
Module title (German)	Topics of Current Research IV
Module title (English)	Topics of Current Research 4
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> Advanced topics of current research in optics and photonics.
Intended learning outcomes	<ul style="list-style-type: none"> Introduction into a field of current research as a basis for further study and research in this field; Independent solution of Exercise problems; Ability to acquire further knowledge by independent literature studies.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMP001 Advanced Quantum Theory	
Module code	PAFMP001
Module title (German)	Fortgeschrittene Quantentheorie
Module title (English)	Advanced Quantum Theory
Person responsible for the module	Prof. Dr. S. Bernuzzi, Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Compulsory module M.Sc. Physik 528 M.Sc. Quantum Science and Technology, required elective module, subject area "adjustment"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • many particle systems, identical particles, non-interacting particles, Thomas-Fermi and Hartree-Fock approximations • addition of angular momenta, Clebsch-Gordan coefficients, selection rules • time-dependent perturbation theory, Fermis golden rule • scattering theory, potential scattering, partial waves, scattering of identical particles • introduction to relativistic quantum mechanics, Poincare transformations, Klein-Gordon and Dirac equations, minimal coupling, non-relativistic approximation • relativistic hydrogen atom, fine structure • path integrals.
Intended learning outcomes	The course covers relevant facts about advanced quantum mechanics which are necessary for an understanding of quantum phenomena and their relevance in all areas of modern physics. The students will learn methods for describing and modeling nonrelativistic and relativistic quantum systems. They will acquire skills to solve demanding problems and deal with complex physical systems.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	e.g. F. Schwabl; W. Nolting; Straumann; K. Gottfried und T.M. Yan; C. Cohen-Tannoudji.
Language of instruction	German, English

Modul PAFMP002 Research Lab	
Module code	PAFMP002
Module title (German)	Physikalisches Experimentieren
Module title (English)	Research Lab
Person responsible for the module	Prof. Dr. T. Fritz
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Compulsory module M.Sc. Physik
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	2 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Labwork: 6 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 120 h 120 h
Content	Planning, execution, evaluation and interpretation of selected experiments chosen from one of the following topics: optics, solid state physics, astronomy, theory, computational physics as offered by the faculty.
Intended learning outcomes	<ul style="list-style-type: none"> • Independent training in a specific physical issue and project planning; • Improvement of experimental skills • logging, evaluation, interpretation and writing a project report; • Presentation of the results in the form of a scientific talk or poster.
Prerequisites for admission to the module examination	Completion of the experiments and project work.
Requirements for awarding credit points (type of examination)	Labwork grade (100%)
Language of instruction	German, English

Modul PAFMP003 Advanced Seminar Gravitational and Quantum Physics	
Module code	PAFMP003
Module title (German)	Oberseminar Gravitations- und Quantentheorie
Module title (English)	Advanced Seminar Gravitational and Quantum Physics
Person responsible for the module	Prof. Dr. B. Brügmann, Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in Gravitational and/or Quantum Theory
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics Required elective module focus „Quantum and Gravitational Theory“ 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Seminar: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	<ul style="list-style-type: none"> • Systematic development of specialized knowledge in the fields of gravitation theory and quantum theory; • Presentation and discussion of current problems of gravitation theory and quantum theory.
Intended learning outcomes	<ul style="list-style-type: none"> • Familiarisation with a specific topic in gravitation or quantum theory; • Independent discovery and evaluation of scientific literature; • Presentation of scientific facts in form of a talk; • In-depth knowledge in the fields of gravitation theory and quantum theory.
Prerequisites for admission to the module examination	Active participation in the seminar discussions
Requirements for awarding credit points (type of examination)	Scientific Talk (100%)
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMP004 Advanced Seminar Solid State Physics / Material Science	
Module code	PAFMP004
Module title (German)	Oberseminar Festkörperphysik/Materialwissenschaft
Module title (English)	Advanced Seminar Solid State Physics / Material Science
Person responsible for the module	Prof. Dr. T. Fritz
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science“
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Seminar: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	<ul style="list-style-type: none"> • Systematic development of specialised knowledge in the fields of solid state physics and materials science; • Presentation and discussion of current solid-state physical and material science problems.
Intended learning outcomes	<ul style="list-style-type: none"> • Familiarisation with a specific topic in solid state physics/material science • Independent discovery and evaluation of scientific literature; • presentation of scientific facts in form of talk; • In-depth knowledge in the fields of solid-state physics and materials science; • scientific discussion.
Prerequisites for admission to the module examination	Active participation in the seminar discussions
Requirements for awarding credit points (type of examination)	Scientific talk (100%)
Language of instruction	German, English

Modul PAFMP005 Advanced Seminar Astronomy/Astrophysics	
Module code	PAFMP005
Module title (German)	Oberseminar Astronomie/Astrophysik
Module title (English)	Advanced Seminar Astronomy/Astrophysics
Person responsible for the module	Prof. Dr. R. Neuhäuser, Prof. Dr. A. Krivov
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Introduction to Astronomy or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M. Sc. Physik Elective module Lehramt Drittfach Astronomie
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	2 h per week Seminar
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	<ul style="list-style-type: none"> • Focus on observational astrophysics: e.g. Infrared astronomy, sub-stellar objects, interferometry, adaptive optics, final stages of stellar evolution, especially neutron stars; Terra Astronomy • Focus in theoretical astrophysics: e.g. astro-physical timescales, temperatures, direct and inverse problems, deterministic and chaotic phenomena, standard models of astrophysics
Intended learning outcomes	<ul style="list-style-type: none"> • learning concepts of observational and theoretical astrophysics; • Independent training in a special field; • Independent discovery and evaluation of scientific literature; • preparing and holding own lectures; • discussion of current research fields; • Systematic development of specialised knowledge in the field of astronomy / astrophysics
Prerequisites for admission to the module examination	Active participation in the seminar discussion
Requirements for awarding credit points (type of examination)	Scientific Talk (100%)

Additional information on the module	One of the two seminars (assigned event) must be attended, either observational astrophysics (winter) or theoretical astrophysics (summer)
Language of instruction	German/English

Modul PAFMP006 Advanced Seminar Optics	
Module code	PAFMP006
Module title (German)	Oberseminar Optik
Module title (English)	Advanced Seminar Optics
Person responsible for the module	Prof. Dr. C. Spielmann
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics“
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Seminar: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	<ul style="list-style-type: none"> • Systematic development of specialized knowledge in the field of modern optical research; • Presentation and discussion of current optical research areas.
Intended learning outcomes	<ul style="list-style-type: none"> • Independent training in a special field; • Independent discovery and evaluation of scientific literature; • presentation of scientific facts; • in-depth knowledge in modern fields of optics.
Prerequisites for admission to the module examination	Active participation in the seminar discussions
Requirements for awarding credit points (type of examination)	Scientific talk (100%)
Language of instruction	German, English

Modul PAFMP090 Introduction to Research Methods	
Module code	PAFMP090
Module title (German)	Einführung in wissenschaftliches Arbeiten
Module title (English)	Introduction to Research Methods
Person responsible for the module	All professors of the PAF
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
ECTS credits	15 CP
Work load:	450 h
- In-class studying	300 h
- Independent studying	150 h
(incl. preparations for examination)	

Modul PAFMP091 Project Planning for the Master Thesis	
Module code	PAFMP091
Module title (German)	Projektplanung zur Masterarbeit
Module title (English)	Project Planning for the Master Thesis
Person responsible for the module	All professors of the PAF
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
ECTS credits	15 CP
Work load:	450 h
- In-class studying	210 h
- Independent studying	240 h
(incl. preparations for examination)	

Modul PAFMQ001 Fundamentals of Quantum information	
Module code	PAFMQ001
Module title (German)	Grundlagen der Quanteninformation
Module title (English)	Fundamentals of Quantum information
Person responsible for the module	Prof. Dr. F. Steinlechner, PD Dr. F. Setzpfandt, Prof. Dr. M. Gärttner
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	none
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, compulsory module ("essentials") 128 M.Sc. Physics: required elective module specialisation "optics" 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	Concepts of quantum information processing <ul style="list-style-type: none"> • introduction to fundamental concepts and the basic formalism • entanglement • application examples • entanglement characterization Hardware for quantum information processing <ul style="list-style-type: none"> • brief review of key physical concepts and applications • basic hardware requirements for information processing optical qubits, gates
Intended learning outcomes	Understanding of fundamental properties of quantum states, their applications and how to characterize them. Knowledge about basic hardware requirements for quantum information processing and example implementations.
Prerequisites for admission to the module examination	Solution of exercise sheets (Scope to be announced at the beginning of the module).

Requirements for awarding credit points (type of examination)	Written examination
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMQ002 Advanced Quantum Information	
Module code	PAFMQ002
Module title (German)	Fortgeschrittene Quanteninformationstheorie und -hardware
Module title (English)	Advanced Quantum Information
Person responsible for the module	Prof. Dr. F. Steinlechner, PD Dr. F. Setzpfandt, Prof. Dr. M. Gärttner
Recommended or expected prior knowledge	Content of "Introduction to Quantum Information"
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, required elective module, subject area "essentials" 128 M.Sc. Physics: required elective module spezialization "optics" 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	Hardware for quantum information processing <ul style="list-style-type: none"> • superconducting qubits, gates, control, manipulation, readout • light-matter interaction • semiconductor qubits (quantum dots, defects) • atoms / quantum Gases • foundations of quantum sensing (sensitivity, noise, standard quantum limit) • Optomechanics Concepts of quantum information processing <ul style="list-style-type: none"> • decoherence • quantum error correction • many-body entanglement advanced concepts
Intended learning outcomes	Knowledge of all eminent concepts for implementing quantum-information systems. Understanding advanced concepts that enable treatment of non-ideal quantum systems.
Prerequisites for admission to the module examination	Solution of exercise sheets (Scope to be announced at the beginning of the module).

Requirements for awarding credit points (type of examination)	Written examination.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMQ007 Quantum Laboratory	
Module code	PAFMQ007
Module title (German)	Quantum Laboratory
Module title (English)	Quantum Laboratory
Person responsible for the module	PD Dr. F. Setzpfandt
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, required elective module, subject area "practical research training" 128 M.Sc. Physics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Practical course
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	Practical training in experimental quantum technologies. Topics cover a broad range from quantum-state generation and characterization, the demonstration of fundamental quantum effects to applications in communication and metrology.
Intended learning outcomes	<ul style="list-style-type: none"> • Introduction to experimental techniques in quantum technologies. • Planning and preparation of a scientific measuring task. • Carrying out scientific lab in optics together with a research team. • Preparation of a scientific report.
Requirements for awarding credit points (type of examination)	Lab mark (100%) Consists of acceptance tests and written reports
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMQ100 Molecular quantum mechanics / quantum chemistry I	
Module code	PAFMQ100
Module title (German)	Molecular quantum mechanics / quantum chemistry I
Module title (English)	Molecular quantum mechanics / quantum chemistry I
Person responsible for the module	Prof. Dr. S. Gräfe, Dr. A. Croy
Recommended or expected prior knowledge	Module „Physical chemistry” or equivalent
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	2 hour lecture, 1 hour exercise per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	In lecture and tutorial, students are taught basics and concepts describing the dynamics of (open) quantum systems (wave packets, density matrix, quantum master equations). Furthermore, aspects of multi-particle physics of molecules are covered, i.e. e.g. multi-electron wave functions, the Hartree-Fock approximation and the role of basis sets.
Intended learning outcomes	Become familiar with the fundamentals of open quantum systems and "ab initio" methods for performing quantum chemical calculations with respect to molecular and nanoscale systems.
Requirements for awarding credit points (type of examination)	Oral or written examination on the material taught in lecture and seminars.
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMQ101 Molecular quantum mechanics / quantum chemistry II	
Module code	PAFMQ101
Module title (German)	Molecular quantum mechanics / quantum chemistry II
Module title (English)	Molecular quantum mechanics / quantum chemistry II
Person responsible for the module	Prof. Dr. S. Gräfe; Dr. A. Croy
Recommended or expected prior knowledge	Module "Molecular quantum mechanics / quantum chemistry I" or equivalent
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization" 128 M.Sc. Physics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	2 hour lecture 1 hour exercise per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Building on Module PAFMQ100, in-depth and advanced knowledge of advanced methods of theoretical chemistry is taught. This includes (time-dependent) density functional theory as well as an introduction to numerical methods, concepts and algorithms for the description of molecular systems that exchange energy and/or charge with their environment.
Intended learning outcomes	Familiarization with advanced methods and concepts, such as DFT/ TDDFT. Understanding numerical methods, concepts and algorithms for describing open quantum systems and their application to molecular and nanoscale systems.
Requirements for awarding credit points (type of examination)	Oral or written examination on the material taught in lecture and seminars.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT001 General Relativity	
Module code	PAFMT001
Module title (German)	Allgemeine Relativitätstheorie
Module title (English)	General Relativity
Person responsible for the module	Prof. Dr. B. Brügmann
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Relativistic Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Fundamentals of general relativity • Einstein field equations • Newtonian approximation • Gravitational waves • Black holes • Cosmology and the big bang
Intended learning outcomes	<ul style="list-style-type: none"> • Obtain knowledge of relativistic gravitational physics • Develop problem solving skills for astrophysical problems in the regime of high velocities and strong gravitational fields
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMT002 Particles and Fields	
Module code	PAFMT002
Module title (German)	Teilchen und Felder
Module title (English)	Particles and Fields
Person responsible for the module	Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Introduction: examples of classical field theories • aspects of classical field theory: Lagrange and Hamilton formalism, Noether theorem and charges • non-linear scalar field theories: $O(N)$ models, spontaneous symmetry breaking, Goldstone theorem • fields / particles as representations of the Lorentz group: classification of representations, spinors, construction of free theories • interactive theories: Yukawa models, QED, Abelian Higgs models • current aspects of field theories in particle physics
Intended learning outcomes	<ul style="list-style-type: none"> • preparation for quantum field theory in the 2nd M.Sc. Semester • comprehension of concepts and methods, and acquiring technical skills for the theoretical treatment of field theories with applications in particle physics
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination or paper (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMT003 Quantum Field Theory	
Module code	PAFMT003
Module title (German)	Quantenfeldtheorie
Module title (English)	Quantum Field Theory
Person responsible for the module	Prof. Dr. M. Ammon
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Particles and Fields or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Principles of relativistic quantum field theories • Quantization of Klein-Gordon , Dirac , and electromagnetic fields • Perturbation theory and Feynman diagrams • S matrix and cross sections • Functional integrals • effective effects and correlation functions • Regularization and renormalization
Intended learning outcomes	<ul style="list-style-type: none"> • Teaching the basic principles and structures of quantum field theories. • Obtaining abilities to describe the interactions of elementary particles and to calculate important scattering and decay processes.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMT010 Advanced Quantum Field Theory	
Module code	PAFMT010
Module title (German)	Fortgeschrittene Quantenfeldtheorie
Module title (English)	Advanced Quantum Field Theory
Person responsible for the module	Prof. Dr. M. Ammon
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Particles and Fields and Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Anomalies in Quantum Field Theory (QFT); • QFT at finite temperature and density; • (Quantum) Phase Transitions; • Near- and non-equilibrium dynamics of QFT; • Introduction to conformal field theory; • Topological objects in quantum field theory.
Intended learning outcomes	Impart thorough knowledge of advanced methods in quantum field theory
Prerequisites for admission to the module examination	Will be announced in the first lecture. Usually 50 per cent of points of the examples sheets or presenting one original paper.
Requirements for awarding credit points (type of examination)	Will be announced in the first lecture: usually oral exam at the end of the semester
Language of instruction	English
Language of instruction	German, English

Modul PAFMT011 Introduction to String Theory and AdS/CFT	
Module code	PAFMT011
Module title (German)	Einführung in Stringtheorie und AdS/CFT
Module title (English)	Introduction to String Theory and AdS/CFT
Person responsible for the module	Prof. Dr. M. Ammon
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Quantum Field Theory and General Relativity or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	Introduction to concepts of string theory and AdS/CFT correspondence, in particular: <ul style="list-style-type: none"> • relativistic bosonic string and its quantization • open strings and D-branes • aspects of conformal field theory • Polyakov path integral • scattering of strings • low energy effective action • dualities in string theory • compactification scenarios • introduction to AdS / CFT • main tests of AdS / CFT • extension and application of AdS / CFT
Intended learning outcomes	Impart thorough knowledge of string theory and AdS/CFT duality
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT012 The Standard Model of Particle Physics	
Module code	PAFMT012
Module title (German)	Das Standardmodell der Teilchenphysik
Module title (English)	The Standard Model of Particle Physics
Person responsible for the module	Prof. Dr. A. Wipf
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	Overview of the standard model of particle physics including: <ul style="list-style-type: none"> • symmetries, quantum electrodynamics • strong interaction • the quark model and quantum chromodynamics • hadrons and asymptotic freedom • weak interactions and the Higgs effect • scattering experiments • limits of the Standard Model
Intended learning outcomes	Impart thorough knowledge of particle physics phenomenology and its fundamental concepts.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul PAFMT013 Gauge Theories	
Module code	PAFMT013
Module title (German)	Eichtheorien
Module title (English)	Gauge Theories
Person responsible for the module	Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • gauge symmetry • classical Yang-Mills theory • quantization of gauge theories / BRST formalism / Gribov problem • perturbation theory • semiclassical expansions • topological configurations • confinement criteria and scenarios
Intended learning outcomes	Comprehension of concepts and methods, and acquiring technical skills for the theoretical treatment of gauge theories with applications in particle physics
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester or term paper
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.

Language of instruction	German, English
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Modul PAFMT014 Lattice Field Theory	
Module code	PAFMT014
Module title (German)	Quantenfeldtheorien auf dem Gitter
Module title (English)	Lattice Field Theory
Person responsible for the module	Prof. Dr. A. Wipf
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 135 h
Content	<ul style="list-style-type: none"> • Path integral for quantum field theories • Euclidean formulation and quantum field theories in thermal equilibrium • Lattice field theory as spin models in Statistical Physics • rigorous results and approximations • stochastic methods, Monte Carlo simulations • renormalization group, critical phenomena • gauge theories on a space-time grid • Quantumchromodynamic on a lattice
Intended learning outcomes	<ul style="list-style-type: none"> • The course covers theoretical concepts and methods necessary to understand (discretized) Quantum Field Theories. • The students will learn stochastic and numerical methods to simulate spin models and lattice field theories. • They will acquire skills to independently develop numerical algorithms to calculate observables in Elementary Particle Physics, Quantum Field Theory and Statistical Physics.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT015 Computational Quantum Physics	
Module code	PAFMT015
Module title (German)	Quantenphysik mit dem Rechner
Module title (English)	Computational Quantum Physics
Person responsible for the module	Prof. Dr. S. Fritzsche
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Theoretical Mechanics, Electrodynamics and Quantum Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 B.Sc. Physics, Required elective module 128 M.Sc. Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Coulomb problem; • particles with spin; • qubits, quantum registers and quantum gates; • representation of pure and mixed states (Bloch sphere); • composite systems, indistinguishable particles; • Hartree-Fock method; • Coupling of angular momenta.
Intended learning outcomes	<ul style="list-style-type: none"> • Learning computer algebraic and numerical methods in the description of simple quantum models; • Ability to independently solve simple models and tasks, formulate pseudo-code and deal with computer algebra systems more efficiently.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written examination or paper (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul PAFMT016 Symmetries in Physics	
Module code	PAFMT016
Module title (German)	Symmetrien in der Physik
Module title (English)	Symmetries in Physics
Person responsible for the module	Prof. Dr. A. Wipf
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Theoretical Mechanics und Quantum Mechanics or equivalent
Type of module (compulsory module, required elective module, elective module)	128 B.Sc. Physics Required elective module 128 M.Sc. Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second year (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • symmetries and groups • space and space-time symmetries • conserved currents and charges • discrete groups and continuous Lie-groups • representations of groups, theory of characters, reductions of representation • invariant integration on Lie-Groups • Lie-algebras and their representations • classification of semi-simple Lie-algebras • selected application of group theory and representation theory in solid state physics, atomic and molecular physics, quantum field theory and particle physics.

Intended learning outcomes	<ul style="list-style-type: none">• The course covers theoretical concepts of discrete and continuous groups, Lie-algebras and their representations with relevant applications in physics• The students will learn how to exploit symmetry principles to simplify or even solve problems in all branches of physics where symmetry principles play a role
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul PAFMT017 Atomic Theory	
Module code	PAFMT017
Module title (German)	Theoretische Atomphysik
Module title (English)	Atomic Theory
Person responsible for the module	Prof. Dr. S. Fritzsche
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 B.Sc. Physics Required elective module 128 M.Sc. Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> • Short review of hydrogenic atoms • Independent-particle model & Hartree-Fock theory • Interaction with the radiation field • Correlated many-body theory • Atomic collision theory • Basics of the density matrix theory • Atoms and forces in (intense) light fields • Laser cooling and trapping; ions traps • Rotating-wave approximation
Intended learning outcomes	Learning the basics of atomic structure and atomic collision processes.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT018 Physics of the Quantum Vacuum in Strong Fields	
Module code	PAFMT018
Module title (German)	Physik des Quantenvakuums in starken Feldern
Module title (English)	Physics of the Quantum Vacuum in Strong Fields
Person responsible for the module	Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> Theoretical foundations of quantum electrodynamics (QED) in strong electromagnetic fields; Derivation of elementary signatures of the strong field QED; Discussion of proposals for their demonstration with current experimental methods.
Intended learning outcomes	Imparting concepts and methods and gaining the skills to deal with quantum electrodynamics issues in strong electromagnetic fields.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester. or term paper
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT019 Supersymmetry	
Module code	PAFMT019
Module title (German)	Supersymmetrie
Module title (English)	Supersymmetry
Person responsible for the module	Prof. Dr. A. Wipf
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Supersymmetric quantum mechanics • symmetries and spinors • Wess Zumino models • Supersymmetry algebra and representations • Superspace and superfields • supersymmetric Yang-Mills theories
Intended learning outcomes	<ul style="list-style-type: none"> • The students will learn the structure and properties of supersymmetric theories and the basics for understanding developments in particle physics and string theory. • They will acquire skills to calculate simple processes in supersymmetric theories.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT020 Physics of Scales - The Renormalisation Group	
Module code	PAFMT020
Module title (German)	Physik der Skalen - Die Renormierungsgruppe
Module title (English)	Physics of Scales - The Renormalisation Group
Person responsible for the module	Prof. Dr. H. Gies
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Quantum Field Theory or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus Gravitation- and Quantum Theory
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 SWS Exercise: 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • perturbative renormalization; • classification of perturbatively renormalizable theories; • proofs of renormalizability; renormalization in statistical systems; • renormalization group equations, • flow equations
Intended learning outcomes	<ul style="list-style-type: none"> • comprehension of concepts and methods, and acquiring technical skills for the theoretical treatment of knowledge about renormalization of quantum field theories and their scale dependencies, long- and short-range behavior of QFTs and statistical systems
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	written or oral examination (100%)
Recommended reading	For example: J. Cardy (Scaling and Renormalization), J. Zinn-Justin (QFT & Critical Phenomena), Peskin, Schroeder; K. Huang (From operators to Path integrals)
Language of instruction	Englisch, German upon common request

Modul PAFMT099 Topics of Current Research: Quantum Field Theory	
Module code	PAFMT099
Module title (German)	Themen der aktuellen Forschung: Gravitations- und Quantenfeldtheorie I
Module title (English)	Topics of Current Research: Quantum Field Theory
Person responsible for the module	Prof. Dr. M. Ammon
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Further, in-depth topics in the field of quantum field theory; • Topics from current areas of research.
Intended learning outcomes	<ul style="list-style-type: none"> • specialisation in a special field of quantum field theory; • Independent handling of exercises; • Ability of literature review.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT200 Numerical General Relativity	
Module code	PAFMT200
Module title (German)	Numerische Relativitätstheorie
Module title (English)	Numerical General Relativity
Person responsible for the module	Prof. Dr. B. Brügmann
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Computational Physics and General Relativity or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Quantum and Gravitational Theory“
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Numerical relativity for black holes and gravitational waves • 3 + 1 decomposition of the 4-dimensional Einstein equations • Numerical treatment of the elliptic initial value problem • Numerical treatment of the time evolution equations
Intended learning outcomes	<ul style="list-style-type: none"> • Basics and methods of the numerical approach to general relativity • Developing skills for independent problem solving in numerical relativity
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	<ul style="list-style-type: none"> • T. Baumgarte and S. Shapiro, Numerical Relativity and Compact Binaries, Phys.Rept. 376 (2003) 41-131; • Alcubierre, Introduction to 3+1 Numerical Relativity (2008).
Language of instruction	German, English

Modul PAFMT201 Gravitational Waves	
Module code	PAFMT201
Module title (German)	Gravitationswellen
Module title (English)	Gravitational Waves
Person responsible for the module	Prof. Dr. B. Brüggemann
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module General Relativity or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Quantum and Gravitational Theory“
Frequency of offer (how often is the module offered?)	Every second year (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Theory of gravitational radiation (radiation field, back reaction) • Astrophysical sources of gravitational waves • Gravitational wave detectors • Analysis of gravitational waves
Intended learning outcomes	<ul style="list-style-type: none"> • Advanced knowledge of physics and astrophysics of gravitational waves • Developing skills for independent problem solving in gravitational wave astronomy
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	For example: <ul style="list-style-type: none"> • Misner/Thorne/Wheeler, Weinberg, Shapiro/Teukolsky, Kenyon, Fließbach, Saulson, • Schutz: Gravitational Wave Data Analysis.

Language of instruction	German, English
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Modul PAFMT202 Computational Physics III	
Module code	PAFMT202
Module title (German)	Computational Physics III
Module title (English)	Computational Physics III
Person responsible for the module	Prof. Dr. B. Brüggmann
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Computational Physics or equivalent
Prerequisite for what other modules	
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Partial Differential Equations: <ul style="list-style-type: none"> • Fundamentals of differential equations • Introduction to elliptic, parabolic and hyperbolic differential equations • explicit and implicit procedures, stability analysis • Poisson equation, diffusion equation, advection equation, wave equation, • shocks; • difference method, • pseudo spectral methods, • multiple grids
Intended learning outcomes	<ul style="list-style-type: none"> • Mastering the basics and methods of partial differential equations and machine learning in physics • Ability to work independently on a numerical project
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Written or oral examination or project (100%) The form of the exam will be announced at the beginning of the semester.
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT203 Magnetohydrodynamics	
Module code	PAFMT203
Module title (German)	Magnetohydrodynamik
Module title (English)	Magnetohydrodynamics
Person responsible for the module	Prof. Dr. R. Meinel
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Quantum and Gravitational Theory“
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Magnetohydrodynamic approximation • Magnetohydrokinematics (induction equation, free decay of magnetic fields, frozen field lines, dynamo problem) • Ideal MHD, magnetohydrostatics • Hartmann flow, magnetohydrodynamic waves, stability studies • Applications in astrophysics (magnetic fields of planets, stars, galaxies, solar physics)
Intended learning outcomes	<ul style="list-style-type: none"> • Teaching the basics and methods of magnetohydrodynamics • Developing skills for independent solving of tasks from this area
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	For example: <ul style="list-style-type: none"> • Landau/Lifschitz Band 8; • F. Cap, Lehrbuch der Plasmaphysik und Magnetohydrodynamik; • D. Lortz, Magnetohydrodynamik; • R. Kippenhahn und C. Moellenhoff, Elementare Plasmaphysik.
Language of instruction	German, English

Modul PAFMT204 Relativistic Astrophysics	
Module code	PAFMT204
Module title (German)	Relativistische Astrophysik
Module title (English)	Relativistic Astrophysics
Person responsible for the module	Prof. Dr. R. Meinel
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module General Relativity or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Quantum and Gravitational Theory“
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Newtonian and relativistic stellar models (Lane-Emden equation, Tolman-Oppenheimer-Volkoff equation) • white dwarfs (equation of state, mass-radius relation, Chandrasekhar limit) • neutron stars • black holes • rotating stars and rotating black holes
Intended learning outcomes	<ul style="list-style-type: none"> • Basic knowledge of relativistic astrophysics • Development of skills of independent solution of tasks from this area
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	For example: Hartle, Shapiro/Teukolsky, Goenner, Straumann, d'Inverno, Landau/Lifschitz, Misner/Thorne/Wheeler.

Language of instruction	German, English
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Modul PAFMT205 Solitons	
Module code	PAFMT205
Module title (German)	Solitonen
Module title (English)	Solitons
Person responsible for the module	Prof. Dr. R. Meinel
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Quantum and Gravitational Theory“
Frequency of offer (how often is the module offered?)	Every second year (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Integrable non-linear equations (eg sine-Gordon equation, Korteweg-de Vries equation, Non-Linear Schrödinger equation, Toda lattice, Ernst equation) • Methods for construction of special exact solutions (for example, n-Solitons-solutions) and to the solution of initial and boundary value problems (Bäcklund and inverse scattering method) • Conservation laws and integrability • Solitons in hydrodynamics, general relativity and non-linear optics
Intended learning outcomes	<ul style="list-style-type: none"> • Teaching the basics and methods of soliton physics • Developing skills for independent solving of tasks from this area
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	For example: <ul style="list-style-type: none"> • G. Eilenberger, Solitons-Mathematical Methods for Physicists; • S. Novikov et al., Theory of Solitons: The inverse scattering method
Language of instruction	German, English

Modul PAFMT206 Computational Physics IV	
Module code	PAFMT206
Module title (German)	Computational Physics IV
Module title (English)	Computational Physics IV
Person responsible for the module	Prof. Dr. B. Brüggmann
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Modules Computational Physics I and II or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Machine Learning in Physics • Basics of Machine Learning, Neural Networks and Deep Learning • Sample Applications in Physics, Pattern Recognition, Time Series Analysis, Monte Carlo Methods
Intended learning outcomes	<ul style="list-style-type: none"> • Mastering the basics and methods of machine learning in physics • Ability to work independently on a numerical project
Prerequisites for admission to the module examination	Processing of exercise sheets (kind and extend will be announced at the beginning of the semester)
Requirements for awarding credit points (type of examination)	Numerical project or written exam (100%); to be announced at the beginning of term
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul PAFMT299 Topics of Current Research: Gravitational Theory	
Module code	PAFMT299
Module title (German)	Themen der aktuellen Forschung: Gravitations- und Quantentheorie II
Module title (English)	Topics of Current Research: Gravitational Theory
Person responsible for the module	Prof. Dr. B. Brügmann
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<ul style="list-style-type: none"> • Further, in-depth topics in the field of gravitation theory; • Topics from current areas of research.
Intended learning outcomes	<ul style="list-style-type: none"> • specialization in the special field of gravitation theory; • Independent handling of exercises; • Ability of literature review.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul PAFMT300 Topics of Current Research: Gravitation- and Quantum Theory III	
Module code	PAFMT300
Module title (German)	Themen der aktuellen Forschung: Gravitations- und Quantentheorie III
Module title (English)	Topics of Current Research: Gravitation- and Quantum Theory III
Person responsible for the module	Prof. Dr. M. Ammon, Prof. Dr. H. Gies, Prof. Dr. S. Flörchinger
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module General Relativity PAFMT001 or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<p>The lecture will cover topics in the foundations of quantum mechanics and with relevance to the interplay between quantum physics and gravity with a focus on nonrelativistic laboratory quantum systems, specifically including topics of current research. In particular, the lecture will cover all or a selection of the following topics:</p> <ul style="list-style-type: none"> • Quantum systems in the gravitational field of the earth, experiments and relativistic generalisation • Decoherence from spacetime fluctuations • The equivalence principle for quantum matter • Theoretical treatment of classically gravitating quantum systems and experimental distinction from a quantised gravitational field • Interpretations of quantum mechanics, the measurement problem, and the potential role of gravity in quantum wave function reduction

Intended learning outcomes	<p>The course should provide the participating students with a profound knowledge on the state of the art of the foundations of quantum mechanics and experimentally established facts on the interplay between gravitational and quantum physics. It should provide them with an overview of different ideas and approaches how to merge the theoretical description of quantum systems with the principles of general relativity, including obstacles and caveats.</p> <p>The advanced level course is ideally taken by Master students who already have some knowledge of general relativity but is open to interested students at all levels with a basic knowledge in quantum mechanics.</p>
Prerequisites for admission to the module examination	None
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Language of instruction	English

Modul PAFMT301 Topics of Current Research: Gravitation- and Quantum Theory IV	
Module code	PAFMT301
Module title (German)	Themen der aktuellen Forschung: Gravitations- und Quantentheorie IV
Module title (English)	Topics of Current Research: Gravitation- and Quantum Theory IV
Person responsible for the module	Prof. Dr. S. Bernuzzi
Recommended or expected prior knowledge	Module General Relativity PAFMT001 or equivalent
Type of module (compulsory module, required elective module, elective module)	128 M.Sc.Physics, Required elective module specialization "Gravitation and Quantum Theory" 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> • Newtonian and Relativistic hydrodynamics Radiation hydrodynamics • Hyperbolic PDEs • Finite volume methods • Riemann problem and solvers • Conservative finite-differencing • Limiters • Galerking methods
Intended learning outcomes	This course covers the development of numerical techniques required to solve the nonlinear equations that arise in the study of Fluid Dynamics. It also covers the analytical background that governs the solutions of these equations. By the end of the course the students will have learned the techniques required to write numerical codes to solve problems in fluid dynamics and relativistic hydrodynamics
Prerequisites for admission to the module examination	None
Requirements for awarding credit points (type of examination)	Written examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul PAFMW019 Applied Materials Thermodynamics	
Module code	PAFMW019
Module title (German)	Werkstoffthermodynamik in der Praxis
Module title (English)	Applied Materials Thermodynamics
Person responsible for the module	PD Dr. S. Lippmann
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying	90 h
(incl. preparations for examination)	

Modul PAFWW006 Electronmicroscopy - Fundamentals and Applications	
Module code	PAFWW006
Module title (German)	Elektronenmikroskopie - Grundlagen und Anwendungen
Module title (English)	Electronmicroscopy - Fundamentals and Applications
Person responsible for the module	PD Dr. S. Lippmann
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	75 h
- Independent studying	75 h
(incl. preparations for examination)	

Modul PAFWW027 Phase Field Theory (intensive)	
Module code	PAFWW027
Module title (German)	Phasenfeldtheorie
Module title (English)	Phase Field Theory (intensive)
Person responsible for the module	Dr. P. Galenko
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
ECTS credits	5 CP
Work load:	150 h
- In-class studying	60 h
- Independent studying	90 h
(incl. preparations for examination)	

Modul PAFMP099 Master thesis	
Module code	PAFMP099
Module title (German)	Masterarbeit Physik
Module title (English)	Master thesis
Person responsible for the module	Professors of Faculty of Physics and Astronomy
Prerequisites for admission to the module	Module Introduction to Research Methods PAFMP090, Project Planning PAFMP091
Type of module (compulsory module, required elective module, elective module)	Compulsory module M.Sc. Physik
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	25 hours a week of practical creative scientific work under the supervision of the supervising professor
ECTS credits	30 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	900 h 500 h 400 h
Content	<ul style="list-style-type: none"> The topic of the material work is determined by the introductory project and can be selected from all branches of physics represented at the Faculty of Physics and Astronomy of university teachers. Development of new scientific knowledge in a branch of physics under guidance
Intended learning outcomes	<ul style="list-style-type: none"> Independent development of knowledge from international specialist literature Scientific work in a research collective according to a plan Summary of scientific results in the Master's thesis Presentation of scientific results Presentation of the results in the form of a scientific lecture or poster.
Requirements for awarding credit points (type of examination)	Master Thesis (100%)
Language of instruction	German, English

Abbreviations:

Abbreviations of lectures

IL....	Inaugural lecture
WG....	Working group
AM....	Advanced module
Exh....	Exhibition
BM....	Basic module
BzPS....	Begleitveranstaltung zum Praxissemester
C....	Consulting
To....	Tour
M....	Meeting
Blo....	Blockage
BC....	Block course
DV....	Slide show
IN....	Introductory session
RS....	Registrations
EC....	Exam course
EX....	Excursion
Exp....	Experiment/survey
FE....	Celebration/festivity
MS....	Movie screening
FEx....	Field exercise
BC....	Basic course
MaS....	Main seminar
MS/ BC....	Main seminar/block course
MaS/ Ex....	Main seminar/exercise
Inf....	Information session
IDS/E....	Interdisciplinary main seminar/ exercise
E....	Exam
KS/ PR....	Klausur/Prüfung
C....	Colloquium
C/I....	Colloquium/practical work
CS....	Conference/symposium
kV....	Kulturelle Veranstaltung

Abbreviations of lectures

Cu....	Course
Co....	Course
Lag....	Lagerung
TRP....	Training research project
RC....	Reading course
M....	Module
ME....	Musical event
AS....	Advanced seminar
OnS....	Online seminar
OnL....	Online lecture
P....	Practical work
I/S....	Practical work/seminar
PM....	Practice module
Sa....	Sample
PJ....	Project
PPD....	Propaedeutic
PS....	Proseminar
E/T....	Exam/test
EPr....	Exam preparation
CSA....	Cross-sectional area
RE....	Revision course
LS....	Lecture Series
TC....	Training course
S....	Seminar
S/E....	Seminar/Excursion
S/E....	Seminar/Exercise
ST....	Service time
Sl....	Conference
SuSch....	Summer school
MISC....	Miscellaneous
OE....	Other event
LC....	Language course
Con....	Convention
TT....	Teleteaching
MN....	Meeting
Tu....	Tutorial
T....	Tutorial
E....	Exercise
E/BC....	Exercise/block course
E....	Exercises

Abbreviations of lectures

E/I....	Exercise/interdisciplinary
E/I....	Exercise/practical work
E/T....	Exercise/tutorial
Conf....	Conference
ViCo....	Video conference
L....	Lecture
L/C....	Lecture with colloquium
L/I....	Lecture/practical work
L/S....	Lecture/seminar
L/E....	Lecture/exercise
Sp....	Speech
TK....	Talk
OS....	Optional seminar
OL....	Optional lecture
Tr....	Training
Wo....	Workshop
WOS....	Workshop
CAC....	Certificate award ceremony

Other Abbreviations

Anm.....	Anmerkung
ASQ....	Allgemeine Schlüsselqualifikationen
AT....	Altes Testament
E....	Essay
FSQ....	Fachspezifische Schlüsselqualifikationen
FSV....	Fakultät für Sozial- und Verhaltenswissenschaften
GK....	Grundkurs
IAW....	Institut für Altertumswissenschaften
LP....	Leistungspunkte
NT....	Neues Testament
SQ....	Schlüsselqualifikationen
SS....	Sommersemester
SWS....	Semesterwochenstunden
TE....	Teilnahme
TP....	Thesenpublikation
ThULB....	Thüringer Universitäts- und Landesbibliothek
VVZ....	Vorlesungsverzeichnis
WS....	Wintersemester