LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Module Catalogue

Master's Programme: Theoretical and Mathematical Physics

(Master of Science, M.Sc.)

(120 ECTS credits)

Based on the *Prüfungs- und Studienordnung*

adopted by the Senate of LMU Munich on June 22, 2023

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Abbreviations and annotations

CP	Credit Points, ECTS credits
ECTS	European Credit Transfer and Accumulation System
h	hours
SoSe	summer semester
SWS	contact hours
WiSe	winter semester
WP	compulsory elective course/module
P	mandatory course/module

1. The ECTS credits assigned in the Module Catalogue are designated as follows: Credit Points not listed in parentheses are awarded when the pertinent examination of the module or module parts have/has been completed successfully. Credit Points in parentheses are listed for calculatory purposes only.

2. The semester for taking a module can either be binding or may be considered as a recommendation, depending on the applicable data in Anlage 2 of the Prüfungs- und Studienordnung for your Programme. In this Module catalogue, the options are indicated as „scheduled semester“ and „recommended semester“.

3. Please note: The Module Catalogue is merely intended to serve as an orientation whereas the provisions of the applicable version of the Prüfungs- und Studienordnung (in German only) of your Programme are legally binding. See: www.lmu.de/studienangebot and select your Programme.

Module: P 1 Transdisciplinary Competences

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Seminar	P 1.1 Presentation of Selected Topics in Theoretical and Mathematical Physics	WiSe and SoSe	30 h (2 SWS)	60 h	(3)
Seminar	P 1.2 Soft Skills	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 6 ECTS credits have to be acquired. Class attendance averages about 4 contact hours. Including time for self-study, 180 hours have to be invested.

Module type	Mandatory module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	None
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	Students familiarize themselves with an aspect of theoretical and mathematical physics and present it to their peers. They balance the importance of various aspects and choose means and media for a successful presentation. A soft skill is a competence that is not part of the scientific subject but related to it. It can for example be acquired in a language course or a programming class or a workshop on skills like scientific writing, business planning or successful job interviews.
Learning outcomes	Participants identify strategies for successful presentations and can implement them. They can get an overview on an advance scientific topic using the available literature and select the most important aspects for their presentation. They can reason about aspects of quality of a presentation and future improvements. In the soft skill, they master basic competences in a critical aspect for their future careers outside the main subjects of their study.
Type of examination	Scientific presentation
Type of assessment	The successful completion of the module will be graded.

Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program coordinator
Language(s)	English
Additional information	None

Module: WP 1 Mathematical Quantum Mechanics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 1.1 Mathematical Quantum Mechanics (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 1.2 Mathematical Quantum Mechanics (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	This module treats the foundations of quantum mechanics and fundamental mathematical properties of Hamilton operators and their spectral theory. It introduces fundamental notions of mathematical quantum mechanics. It discusses principles of quantum mechanics and measurement (EPR paradox and Bell's inequality) and mathematical foundations of unbounded and self-adjoint operators (domain of definition, graphs, adjoints, spectrum, criteria for self-adjointness, spectral theorem, quadratic forms). Then Coulomb-Schrödinger operators, the essential spectrum,

	invariance under compact perturbations and the minimax principle will be presented. This is followed by elements of the theory of many-particle systems (density functional theory, second quantization, glimpses of quantum field theory) and its applications (e.g. Hartree-Fock approximation, superconductivity and superfluidity). At the end the basics of scattering theory (one-particle problems, the existence of wave operators) will be discussed.
Learning outcomes	It is the aim to convey the subjects of the module to empower students to apply them in their research projects. They undstand analytical methods and can apply them to quantum mechanics.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Christian Hainzl
Language(s)	English
Additional information	None

Module: WP 2 Differential Geometry

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 2.1 Differential Geometry (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 2.2 Differential Geometry (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	BSc Mathematik; MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Manifolds, vector fields and flows, Lie groups and Lie algebras, tensors and differential forms, vector bundles and connections, Riemannian metrics and curvature, model spaces of constant curvature, homogeneous spaces, Einstein manifolds. In particular, it discusses submanifolds of Euclidean space, foliations, distributions, Frobenius' theorem, multilinear algebra, partitions of unity, orientations, integration on manifolds, Stokes' theorem, de Rham cohomology.

Learning outcomes	The main goal of the module is to become acquainted with the basic concepts of modern differential geometry and some of its physical applications. With this knowledge students can properly understand basic problems in geometry and pursue futher studies in advanced courses in geometry.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 3 Quantum Field Theory

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 3.1 Quantum Field Theory (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 3.2 Quantum Field Theory (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	• Basic Concepts of Quantum Field Theory • Path integral representation of quantum field theory, perturbation expansion, Feynman diagrams • From Green functions to scattering cross sections, particle states, LSZ reduction • Renormalization, regularization, effective field theory, renormalization group, running couplings • Symmetries and relativistic particles & quantum fields with spin, fermionic path integral, Feynman rules for general fields

	• Vector fields and gauge symmetry, quantum electrodynamics
Learning outcomes	After successful completion of the module the student will be prepared to compute Green functions in perturbation theory, including loop corrections, and apply these to calculations of high-energy reactions; to quantise non-Abelian gauge theory and to calculate tree- and loop processes; to understand the concepts of regularisation and renormalisation and to apply these in calculations; to improve perturbative calculations using the renormalisation group; to construct effective quantum field theories.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Martin Beneke
Language(s)	English
Additional information	None

Module: WP 4 Theoretical Solid State Physics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 4.1 Theoretical Solid State Physics (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 4.2 Theoretical Solid State Physics (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics; MSc Quantum Science and Technology
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The aim of this module is to learn established and modern concepts in theoretical condensed matter physics. The contents of this module vary somewhat from year to year, depending on the preferences of the lecturer; interested students are advised to contact the lecturer in advance for details. A typical module could be structured as follows: It starts with a brief recapitulation of crystal structures and classification, then addresses X-ray elastic scattering and neutron inelastic scattering and discusses static and dynamic structure factors. Next come phonons, followed by

	tight-binding models (e.g. the dispersion of graphene and polyacetylene), also highlighting the consequences of inversion symmetry, time reversal symmetry, and spin-obit coupling. Next is a phenomenological discussion on semiconductors. The second half of the module is devoted to the integer quantum Hall effect, the Berry phase and the role of topology, topological insulators and the fractional quantum Hall effect. Further optional topics include Anderson localization, magnetism or BCS superconductivity. The module does not use techniques from field theory.
Learning outcomes	The main goal of this module is to give an overview over the many phenomena in modern condensed matter theory from a material-specific point of view. After successful completion of the module students are able to: - understand X-ray and neutron scattering; - understand the role of symmetry and topology in band structures; - compute phonon and tight-binding spectra; - explain the working of semiconductors; - compute the Berry phase; - understand the bulk-edge correspondence in topological materials; - work with Laughlin wavefunctions and composite fermions; work through advanced condensed matter physics topics on their own.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 5 Introduction to Partial Differential Equations

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 5.1 Introduction to Partial Differential Equations (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 5.2 Introduction to Partial Differential Equations (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	BSc Mathematik; MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The module first introduces the method of separation of variables and the Fourier method to solve initial value problems for the heat and wave equations. Then first order differential equations will be discussed. The module continues with the n-dimensional heat equation, especially with the representation of the solution, uniqueness and maximum principle. Next d'Alembert and Poisson formulas, Hadamard's descent method, finite speed of propagation and Huygens' principle for n-dimensional wave

	equations will be introduced. Finally, the n-dimensional Poisson equation, the Green representation formula, the mean value property of the Poisson integral formula, the maximum principle, Perron's method and variational methods will be discussed. A number of geometric problems and numerous phenomena that are modelled in the natural science and increasingly also in economic sciences, lead to partial differential equations. The main goal of the module is to explore the existence, uniqueness and fundamental properties of the classic solutions of three main types of 2nd order partial differential equations.
Learning outcomes	Students become familiar with basic questions and methods of partial differential equations. They are able to understand mathematical processes and see them in the framework of partial differential equations.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Christian Hainzl
Language(s)	English
Additional information	None

Module: WP 6 Quantum Electrodynamics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 6.1 Quantum Electrodynamics (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise	WP 6.2 Quantum Electrodynamics (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Canonical quantization, Klein-Gordon and Dirac fields, gauge principle and QED Lagrangian, S-matrix, Feynman rules, basic QED processes, radiative corrections.
Learning outcomes	The module aims to convey a detailed understanding of QED and the ability to perform concrete perturbative calculations of elementary processes.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Georgi Dvali
Language(s)	English
Additional information	None

Module: WP 7 General Relativity

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 7.1 General Relativity (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 7.2 General Relativity (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Introduction to the differential geometry: manifolds, vectors and tensors, connection, metric, geodesics and curvature. Furthermore, the equivalence principle, special relativity, propagation of light and redshift, Einstein's equations, Newtonian limit of General Relativity, coordinates conditions Cauchy problem, spherically symmetric gravitational field and Schwarzschild solution, perihelion shift and deviation of light, weak gravitational field and post-newtonian approximation, gravitational waves, black holes are discussed.

Learning outcomes	The aim of the module is an acquaintance with the basic concepts of General Relativity and familiarity with the most important concepts of differential geometry.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Viatcheslav Mukhanov
Language(s)	English
Additional information	None

Module: WP 8 Topology I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 8.1 Topology 1 (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 8.2 Topology 1 (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Covering spaces and singular homology theory, in particular basic notions of set theoretic topology, homotopy, fundamental group, Seifert and van Kampen's theorem, coving theory, universal covering, classification of coverings, Hurewicz' theorem, CW complexes, cellular homology, classical theorems of topology.
Learning outcomes	The module aims to give an introduction to the basic concepts and methods of both differential and algebraic topology.

Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 9 String Theory I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 9.1 String Theory 1 (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 9.2 String Theory 1 (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	This module gives an introduction into the theory of closed strings (Nambu-Goto action, Polyakov action) in terms of a two-dimensional conformal field theory. It describes the various approaches to quantization and introduces compactifications on tori. Later, the discussion is extended to open strings and D-branes and the relation between string theory and its low energy description in terms of an effective field theory is developed. It gives an outlook to modern topics in target space like dualities, M-Theory, AdS/CFT correspondence.

Learning outcomes	The main goals of this module are an understanding of the fundamental aspects of perturbative bosonic strings in the framework of a two-dimensional conformal world-sheet theory and its relation to quantum field theories.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 10 Selected Topics in Theoretical and Mathematical Physics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 10.1 Lecture on Selected Topics in Theoretical and Mathematical Physics 1	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 2 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	In this course, selected special topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	This course provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 11 Block Lecture on Selected Topics in Theoretical and Mathematical Physics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 11.1 Block Lecture on Selected Topics in Theoretical and Mathematical Physics 1	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	In this course, selected special topics in theoretical and mathematical physics are presented in an intensive format. Special attention is paid to recent developments in research.
Learning outcomes	This course provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 12 Summer School on Selected Topics in Theoretical and Mathematical Physics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 12.1 Summer School on Selected Topics in Theoretical and Mathematical Physics 1	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 1
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected special topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	Schools serve to broaden the scientific view by an intense treatment of a wide spectrum of topics in a limited amount of time.

Type of examination	Written exam or oral examination or term paper or scientific protocol or presentation or poster
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 13 Advanced Course on Selected Topics in Theoretical and Mathematical Physics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Seminar	WP 13.1 Seminar on Selected Topics in Theoretical and Mathematical Physics 1	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 2 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	In this course, selected topics in theoretical and mathematical physics are presented by the student participants. Special attention is paid to recent developments in research. Participants extend their previously acquired presentation skills
Learning outcomes	This course provides an in-depth discussion of a specific topic aiming to make contact with ongoing research. Students further improve and extend their abilities to present an advanced scientific topic using appropriate methods.

Type of examination	Presentation
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 14 Selected Topics in Theoretical and Mathematical Physics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 14.1 Lecture on Selected Topics in Theoretical and Mathematical Physics 2	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 2 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	In this course, selected topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	This course provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 15 Block Lecture on Selected Topics in Theoretical and Mathematical Physics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 15.1 Block Lecture on Selected Topics in Theoretical and Mathematical Physics 2	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	In this course, selected special topics in theoretical and mathematical physics are presented in a condensed format. Special attention is paid to recent developments in research.
Learning outcomes	This course provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 16 Summer School on Selected Topics in Theoretical and Mathematical Physics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 16.1 Summer School on Selected Topics in Theoretical and Mathematical Physics 2	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected special topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	Schools serve to broaden the scientific view by an intense treatment of a wide spectrum of topics in a limited amount of time.

Type of examination	Written exam or oral examination or term paper or scientific protocol or presentation or poster
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 17 Mathematical Statistical Physics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 17.1 Mathematical Statistical Physics (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 17.2 Mathematical Statistical Physics (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The course covers the following topics: Gibbs measures: DLR conditions, existence, uniqueness (Dobrushin's theorem), phase transitions, absence of spontaneous symmetry breaking in two dimensions. Ising model: high temperature phase, Peierls argument, cluster expansion, Fortuin-Kasteleyn representation, FKG inequality, spontaneous symmetry breaking in continuous models. Non-equilibrium model systems: Exclusion processes, matrix product ansatz, interacting particle systems. The main goal of this course is to acquire a deeper mathematical and physical understanding

	of phase transitions and collective phenomena that occur in macroscopic interacting particle systems.
Learning outcomes	The main goal of this course is to acquire a deeper mathematical and physical understanding of phase transitions and collective phenomena that occur in macroscopic interacting particle systems.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Franz Merkl
Language(s)	English
Additional information	None

Module: WP 18 Mesoscopic Physics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 18.1 Mesoscopic Physics (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 18.2 Mesoscopic Physics (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module covers the following topics: Electrical conductance as scattering problem and conductance quantization, quantum Hall effect, quantum dots as "artificial atoms", tunneling, Coulomb blockade and single electron transistor, disorder effects (random matrix theory and weak localization), shot noise and full counting statistics of electronic transport, dephasing and partially coherent transport, mesoscopic superconductivity (e.g. Josephson arrays and qubits), interacting electrons in one dimension ("Luttinger liquid"), spin effects (e.g. spin-orbit scattering and Kondo effect), relation to quantum optics and the physics of

	ultracold atoms. This module offers an introduction to one of the central modern areas of theoretical condensed matter physics.
Learning outcomes	The main goal is to acquire a fundamental understanding of how the behavior of electrons in meso- and nanoscopic systems is governed by the interplay of quantum mechanical interference, the Coulomb interaction and fluctuations.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 19 Many Body Theory

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 19.1 Many Body Theory (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 19.2 Many Body Theory (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics, MSc Quantum Science and Technology
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The aim of this module is to learn basic methods of modern quantum many-body theory and to apply them to various problems in condensed matter physics. The contents of this module vary somewhat from year to year, depending on the preferences of the lecturer; interested students are advised to contact the lecturer in advance for details. A typical module could be structured as follows: It starts with an introduction to second quantization and its application to paradigmatic models of interacting electrons, such as the Hubbard- and Heisenberg models, the Bogoliubov theory of weakly interacting bosons, Hartree-Fock mean-field theory and the

	Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity. The subsequent, main part of this module develops functional integral techniques for bosons and fermions in the finite-temperature Matsubara formalism, discusses Green's functions and their analytic properties, and introduces perturbation theory using Feynman diagrams and elementary non-perturbative methods such as the Hubbard-Stratonovich transformation. These methods are then used to study properties of interacting electron systems (random-phase approximation, screening and plasmon excitations) and to discuss Fermi liquid theory. The next chapter covers the linear response formalism (Kubo formula) as the central tool to establish a connection between theoretically computable correlation functions and experimental observables. The final core topic is an extended discussion of the BCS theory of superconductivity, starting from the functional integral representation.
Learning outcomes	After completing the Module the student is able to: - Understand and apply the formalism of second quantization to study interacting quantum many-particle systems. - Explain the main ideas behind common approximation schemes, in particular mean-field theory and the Bogoliubov transformation. - Understand the functional integral representation of partition functions, manipulate functional integrals, and apply a Hubbard-Stratonovich decoupling. - Explain the properties of Green's functions and their use in diagrammatic perturbation theory. - Understand and use the linear response formalism to compute experimental observables of interacting many-particle systems. - Understand the theory of BCS superconductivity. - Follow current research topics and use the toolbox of many-body methods to start independent research.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 20 Quantum Optics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 20.1 Quantum Optics (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 20.2 Quantum Optics (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The following systems will be considered: trapped ions, neutral atoms in magnetic and optical traps, thermal ensembles of atoms and photons. Applications in the field of quantum information processing as well as in Bose-Einstein condensation will also be described. Quantum optics deals with the interaction of light and matter (atoms and molecules). During the last few years, this topic has acquired a renewed interest through the experimental achievements made in atomic physics, and the possibility of controlling and manipulating atomic quantum states

	using light. This module will review the theoretical techniques used to describe the interactions of light with atoms, as well as the physical phenomena observed in actual experiments dealing with cold atoms.
Learning outcomes	The main goal is to acquire an overview over the multitude of quantum optical effects and the most important methods for their theoretical description.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 21 Advanced Mathematical Quantum Mechanics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 21.1 Advanced Mathematical Quantum Mechanics (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 21.2 Advanced Mathematical Quantum Mechanics (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module offers an overview on advanced chapters of mathematical quantum mechanics. First semiclassical approximations, WKB-calculus, pseudodifferential operators and the Wigner formalism will be discussed. Then basic properties of periodic quantum systems will be presented, among others, the Bloch decomposition, eigenvalues and eigenfunctions of one-body Schrödinger operators and asymptotic eigenvalue statistics as well as mathematical

	descriptions of classical and quantized magnetic fields. Next the static problems of many body systems (theory of large atoms for fermionic systems and Bose-Einstein condensation for bosonic systems) will be presented, followed by the dynamical problems of many body systems (scattering theory, asymptotic completeness, correlation functions, BBGKY-hierachy). At the end, disordered quantum systems and Anderson-localization will be discussed.
Learning outcomes	The main goal of this module is to offer an overview of the most successful current research directions for quantum problems that can be tackled by rigorous mathematical methods.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Chrisitan Hainzl
Language(s)	English
Additional information	None

Module: WP 22 Advanced Partial Differential Equations

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 22.1 Advanced Partial Differential Equations (Lecture)	WiSe or SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 22.2 Advanced Partial Differential Equations (Exercise Course)	WiSe or SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module introduces the following subjects: First order partial differential equations (method of characteristics, Hamilton's equations, Hamilton-Jacobi equation); Fourier transform (Schwartz space, distributions, Sobolev spaces, weak solutions); Second order linear partial differential equations (wave equation, diffusion equation, method of stationary phase and Maxwell equations, geometric optics, Schrödinger equation, inverse problems);

	nonlinear equations (minimal surfaces, variational methods, Monge-Ampere equation, reaction-diffusion equations, Stefan problems, Euler and Navier-Stokes equations, nonlinear heat and Schrödinger equation, Einstein equation). The module develops modern mathematical tools and applies them to the most important partial differential equations that have a direct physical origin.
Learning outcomes	The aim of the module is to familiarise students with advanced questions and methodological approaches in the theory of partial differential equations. With the acquired knowledge, they are able to work independently in this field. The acquired knowledge is the prerequisite for scientific work in this field.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Chrisitan Hainzl
Language(s)	English
Additional information	None

Module: WP 23 Quantum Chromodynamics and the Standard Model of Elementary Particle Physics

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 23.1 Quantum Chromodynamics and the Standard Model of Elementary Particle Physics (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 23.2 Quantum Chromodynamics and the Standard Model of Elementary Particle Physics (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Quarks and leptons, symmetry principles, non-abelian gauge theories, path integral quantization, quantum chromodynamics, asymptotic freedom, deep inelastic scattering, Higgs mechanism, electroweak interactions, flavor physics, anomalies.

Learning outcomes	This module aims to convey the fundamentals of quantum chromodynamics and the standard model.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Georgi Dvali
Language(s)	English
Additional information	None

Module: WP 24 Supersymmetry

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 24.1 Supersymmetry (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 24.2 Supersymmetry (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module introduces the fundamental properties of Supersymmetry. It covers supersymmetric quantum mechanics, SUSY algebra and its representations, supersymmetric field theories and superfield formalism, supersymmetric gauge theories. It explains the special features of supersymmetric theories compared to ordinary theories. This includes a discussion of the Witten index in SUSY quantum mechanics, path integral localization in SUSY QM, as well as applications in quantum field theories, such as non-renormalization arguments, role of BPS sectors, Seiberg-Witten theory.

Learning outcomes	After successful completion of this course the students are able to: 1. State basic definitions: Lie algebra, graded Lie algebra, vector space, graded vector space, representation. 2. Construct spinor representations and (extended) SUSY algebras 3. Construct supersymmetric Lagrangians 4. Compute the Witten index in SUSY QM, explain its invariance under deformations. 5. Compute path integrals in simple SUSY QM models. 6. Compute classical moduli spaces of SUSY gauge theories
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 25 Lie Groups and their Representations

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 25.1 Lie Groups and their Representations (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 25.2 Lie Groups and their Representations (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The aim of this module is to provide mathematical methods needed to describe symmetries in physics. For illustration, we will also discuss physical applications. The module starts with a hands-on discussion of finite groups and their representations. We introduce and define basic concepts (groups, representations, reducible/irreducible,...), provide proofs of elementary theorems (Schur's lemma, Maschke's theorem) and introduce techniques in representation theory (in particular, how to decompose a representation into irreducibles). In the second part, we discuss Lie groups and their representations,

	focussing on Matrix Lie groups, and state theorems such as the Peter-Weyl theorem and Schur-Weyl duality. We emphasize similarities between compact Lie groups and finite groups. The third part of the course discusses Lie algebras, focussing mainly on semi-simple complex Lie algebras. We discuss and explain their structure, partially include proofs, ending up with the classification theorem. Basics of the representation theory will also be covered. Physics applications covered in the module include selection rules for molecules, crystal field splitting, as well as the symmetry of hadrons.
Learning outcomes	After successful completion of the module the students are able to: • State basic mathematical definitions: group, algebra, Lie algebra, representation. • Understand the natural structure preserving maps between these concepts. • Decompose representations of finite groups into irreducible ones using the character table • Associate a Dynkin diagram to a complex semi-simple Lie algebra • Read off a complex semi-simple Lie algebra from a Dynkin diagram • Understand the meaning and importance of theorems on compact Lie groups (Peter-Weyl-theorem, Schur-Weyl duality) • Apply group theory to quantum mechanical systems
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 26 Mathematical Gauge Theory I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 26.1 Mathematical Gauge Theory 1 (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 26.2 Mathematical Gauge Theory 1 (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Geometry and topology of fiber bundles, connections and curvature, Chern-Weil theory of characteristic classes, gauge transformations, gauge invariant functionals on spaces of connections.
Learning outcomes	This module aims to convey competence in the use of the language of fiber bundles, and an understanding of the concepts of curvature, gauge invariance, and characteristic classes.

Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 27 Cosmology

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 27.1 Cosmology (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 27.2 Cosmology (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Kinematics and dynamics of the expanding universe. This includes propagation of light and horizons, hot universe, nucleosynthesis, recombination, the very early universe, inflation, gravitational instability in the Newtonian theory, small perturbations according to general relativity, quantum fluctuations as the origin of the large scale structure of the universe, CMB fluctuations.
Learning outcomes	The module aims to convey acquaintance with the basic concepts of cosmology.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Viatcheslav Mukhanov
Language(s)	English
Additional information	None

Module: WP 28 Topology II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 28.1 Topology 2 (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 28.2 Topology 2 (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: cohomology theories; Poincare duality for manifolds; de Rham theory; characteristic classes.
Learning outcomes	The goal is to acquire a deepened understanding of advanced topics in topology.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.

Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 29 String Theory II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 29.1 String Theory 2 (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 29.2 String Theory 2 (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module begins by developing important concepts such as D-branes, supersymmetric compactifications on orientifolds, orbifolds and Calabi-Yau spaces. Further topics are the computation of string amplitudes (tree-level, 1-loop, automorphic functions), string dualities (M-theory, S-duality, mirror symmetry) and extra dimensions.
Learning outcomes	The main goals of this module are to master perturbative superstring theory and to understand basic non-perturbative properties.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 30 Instantons

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 30.1 Instantons (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 30.2 Instantons (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	After an introduction of the mathematical concepts (topological charge, solitons), the basic examples non-perturbative classical solutions in various dimensions like monopoles (Dirac, t'Hooft-Polyakov) and instantons are discussed. Then their role in quantized theories is highlighted, in particular for symmetry breaking, anomalies and CP-violation. In the following, the properties of solitons and instantons in supersymmetric theories (BPS states) are treated.
Learning outcomes	Students can reason about field theories beyond perturbation theory. They can successfully apply notions from topology to classical and quantum theories.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 31 Black Holes

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 31.1 Black Holes (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 31.2 Black Holes (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The course derives classical black hole solutions (Schwarzschild, Reissner-Nordström, Kerr and their higher dimensional generalizations) and discusses their conformal structure. Global techniques are presented and used to discuss singularity theorems and black hole thermodynamics.
Learning outcomes	Students are familiar with axisymmetric and stationary solutions to Einstein's equations and their physical properties. They can derive Penrose diagrams and use them to argue about global structure of a space-time solution. They have mastered the basic notions about global

	techniques and how they can be used to obtain singularity theorems. They can reason about black holes as thermodynamic objects.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 32 Symplectic Geometry II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 32.1 Symplectic Geometry 2 (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 32.2 Symplectic Geometry 2 (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module deals with almost complex structures, holomorphic curves, Gromov-Witten invariants, quantum cohomology, Floer homology and symplectic field theory.
Learning outcomes	The main goal of this module is the understanding of moduli spaces of holomorphic curves and field theoretic invariants arising from them, as well as their geometric applications.
Type of examination	Written exam or oral examination

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 33 Complex Geometry

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 33.1 Complex Geometry (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 33.2 Complex Geometry (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module deals with Hodge-theory and Kähler manifolds. It discusses elliptic operators and Hodge decomposition on compact manifolds, Laplace operator, harmonic analysis, Bochner technique, complex manifolds, complex and holomorphic vector bundles, Kodaira-Serre duality, Kähler manifolds, natural differential operators, additional structure on cohomology, Hodge and Lefschetz decomposition, Kodaira embedding theorem.

Learning outcomes	The main goals of this module are the knowledge of the interplay of complex analytic and geometric structures on a manifold and the relation to algebraic as well as topological aspects, and the knowledge of some classes of examples (e.g. Calabi-Yau-manifolds) which occur in string theory.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 34 Physics of Soft Condensed Matter and Critical Phenomena

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 34.1 Physics of Soft Condensed Matter and Critical Phenomena (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 34.2 Physics of Soft Condensed Matter and Critical Phenomena (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Mean-field theory, field theories, critical phenomena and renormalization group, generalized elasticity (XY model, liquid crystals, gels), hydrodynamics, topological defects, walls, kinks and solitions, response theory and nonequilibrium thermodynamics.

Learning outcomes	The module aims to convey a fundamental understanding the collective phenomena occurring in macroscopic particle systems in condensed matter.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Erwin Frey
Language(s)	English
Additional information	None

Module: WP 35 Probability Theory

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 35.1 Probability Theory (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 35.2 Probability Theory (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	Bachelor Mathematik, Bachelor Wirtschaftsmathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	BSc Mathemtaik; BSc Wirtschaftsmathematik; MSc Mathematik
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module discusses supplements to measure theory, Borel-Cantelli, 0-1-law, additions to the laws of large numbers and to the central limit theorem, large deviations, law of iterated logarithm, conditional expectations and stochastic kernels, martingales, limit theorems.
Learning outcomes	The module aims to convey familiarity with the measure theoretic construction of probability theory and the

	fundamental limit theorems as well as the ability to understand advanced topics in stochastics.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Porf. Dr. Franz Merkl
Language(s)	English
Additional information	None

Module: WP 36 Stochastic Integration and Stochastic Differential Equations

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 36.1 Stochastic Integration and Stochastic Differential Equations (Lecture)	SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 36.2 Stochastic Integration and Stochastic Differential Equations (Exercise Course)	SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Doob inequalities, Doob-Meyer decomposition in continuous time, quadratic variation and covariation, Ito isometry and stochastic integral with semimartingales as integrator, Ito formula in the general case, Stratonovich integral, Ito calculus, stochastic treatment of parabolic and elliptic PDEs, Levy's theorem, random time changes in stochastic integrals. Further

	topics are change of measure: Girsanov's theorem, white noise, stochastic differential equations: existence and uniqueness of strong solutions, weak solutions.
Learning outcomes	The module aims to convey familiarity with the methods of modern stochastic analysis, especially in the analysis of stochastic phenomena in continuous time. Students master the topics of the lectures and can transfer their knowledge to new problems. Students solve homework problems and present and discuss their solutions in the exercise classes.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Franz Merkl
Language(s)	English
Additional information	None

Module: WP 37 Current Research Topics in Advanced and Applied Quantum Mechanics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 37.1 Current Research Topics in Advanced and Applied Quantum Mechanics 1 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 37.2 Current Research Topics in Advanced and Applied Quantum Mechanics 1 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of advanced and applied quantum mechanics.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of advanced and applied quantum mechanics.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Deft
Language(s)	English
Additional information	None

Module: WP 38 Current Research Topics in Quantum Field Theory and Gauge Theories I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 38.1 Current Research Topics in Quantum Field Theory and Gauge Theories 1 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 38.2 Current Research Topics in Quantum Field Theory and Gauge Theories 1 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of Quantum Field Theory and Gauge Theories.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Quantum Field Theory and Gauge Theories.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Georgi Dvali
Language(s)	English
Additional information	None

Module: WP 39 Current Research Topics in Cosmology, General Relativity, and Differential Geometry I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 39.1 Current Research Topics in Cosmology, General Relativity, and Differential Geometry 1 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 39.2 Current Research Topics in Cosmology, General Relativity, and Differential Geometry 1 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fieds of Cosmology, General Relativity, and Differential Geometry.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Cosmology, General Relativity, and Differential Geometry.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Viatcheslav Mukhanov
Language(s)	English
Additional information	None

Module: WP 40 Current Research Topics in String Theory and Geometry I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 40.1 Current Research Topics in String Theory and Geometry 1 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 40.2 Current Research Topics in String Theory and Geometry 1 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of String Theory and Geometry.
Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of String Theory and Geometry.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 41 Current Research Topics in Statistical Physics and Stochastics I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 41.1 Current Research Topics in Statistical Physics and Stochastics 1 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 41.2 Current Research Topics in Statistical Physics and Stochastics 1 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 2
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of Statistical Physics and Stochastics.
Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Statistical Physics and Stochastics.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Erwin Frey
Language(s)	English
Additional information	None

Module: P 2 Introduction to Scientific Research

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Training	P 2.1 Theoreticum	WiSe and SoSe	120 h (8 SWS)	240 h	(12)
Seminar	P 2.2 Research Seminar	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 15 ECTS credits have to be acquired. Class attendance averages about 10 contact hours. Including time for self-study, 450 hours have to be invested.

Module type	Mandatory module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	None
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module covers selected topics of a chapter in theoretical and mathematical physics. A special focus is on recent developments in these areas. After initial guidance, participants independently investigate their subject and find appropriate literature. They select the most relevant aspects and present those to their peers.
Learning outcomes	Participants are able to independently understand an advanced topic so far unknown to them. They can present their learnings to a group in a concise manner and choose the appropriate means to this end. They can identify and apply criteria for good presentations.
Type of examination	Scientific protocol
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.

Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 42 Condensed Matter Field Theories

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 42.1 Condensed Matter Field Theories (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 42.2 Condensed Matter Field Theories (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics, MSc Quantum Science and Technology
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module develops advanced methods to study interacting quantum many-particle systems in and out of equilibrium. The contents of this module vary somewhat from year to year, depending on the preferences of the lecturer; interested students are advised to contact the lecturer in advance for details. A typical module could be structured as follows: It starts with a short recapitulation of field theoretical fundamentals, in particular functional integral techniques. The next part of the module introduces the renormalization group as a central tool for understanding

	effective low-energy properties of interacting quantum many-particle systems. Topics include scaling, perturbative renormalization, RG flows and fixed points, as well as the Kondo effect and the superfluid-Mott insulator transition as examples. The module then covers fundamentals of low-dimensional systems (Luttinger liquids, bosonization) and the Keldysh technique to study many-particle systems out of equilibrium. Final topics include instantons and non-perturbative techniques as well as optional topics, such as the quantum Hall effect (integer and fractional), Chern-Simons theory, disorder in many-particle systems, high-Tc superconductivity and quantum phase transitions.
Learning outcomes	After completing the Module the student is able to: - Explain the basic ideas of a renormalization group transformation. - Understand the concept of RG flows and RG fixed points. - Perform perturbative renormalization group computations. - Explain what the Kondo effect is. - Use bosonization to understand properties of low-dimensional quantum systems. - Explain how the Keldysh formalism is used to study non-equilibrium phenomena. - Explain what an instanton is. - Follow current research topics and use the toolbox of renormalization group methods to start independent research.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 43 Quantum Information Processing

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 43.1 Quantum Information Processing (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 43.2 Quantum Information Processing (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics, MSc Quantum Science and Technology
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	Quantum Information offers an introduction to the theoretical foundations of Quantum Science and Technology. The course starts with a brief motivation and an introduction to fundamental concepts and the basic formalism (pure/mixed states, evolution, completely positive maps, measurements Schmidt decomposition, tomography, quantum estimation, hypothesis testing). Then the concept of entanglement is discussed in detail, including the distinction between pure and mixed-state entanglement, entanglement entropy, quantification and conversion. Subsequently, some of the

	revolutionary promises of exploiting entanglement are presented, including dense coding, quantum teleportation and quantum cryptography. Next the Bell inequalities, characterizing the quantum weirdness of entanglement and nonlocality, are introduced and discussed in detail. Subsequent chapters cover central applications of quantum information theory: quantum computation, quantum algorithms such as those of Deutsch, Shor and Grover, quantum simulation, and quantum metrology. Final core topics are decoherence, Lindbladian descriptions thereof, and error correction schemes to counteract the consequences of decoherence and protect fragile quantum information. The module will typically also include one or more optional topics, such as many-body entanglement, topological quantum computation, quantum complexity, or tensor networks, which link quantum information theory to many-body physics.
Learning outcomes	After participation in the Module the student is able to: - Explain fundamental concepts such as the distinction between pure and mixed states, quantum evolution, completely positive maps, and quantum measurements. - Explain and quantify the notion of entanglement in various contexts (pure states, mixed states, purification, Bell inequalities). - Understand and explain central applications of quantum information theory, such as quantum cryptography, quantum computation, quantum simulation, and quantum metrology. - Understand the central ideas underlying different quantum algorithms. - Understand the notion and the consequences of decoherence, model it using Lindbladians, and explain central elementary error correction strategies. - Competently perform quantum mechanical computations relevant for the above topics.
xercise type	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Delft
Language(s)	English
Additional information	None

Module: WP 44 Mathematical Gauge Theory II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 44.1 Mathematical Gauge Theory 2 (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 44.2 Mathematical Gauge Theory 2 (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Four-dimensional geometry and self-duality, Yang-Mills-Higgs functionals and the first and second order Yang-Mills equations, Donaldson invariants, Seiberg-Witten theory, selected applications to four-manifolds.
Learning outcomes	The central aim is to develop an understanding for the application of ideas from physics to pure mathematics.
Type of examination	Written exam or oral examination

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 45 Quantum Field Theory on Curved Space-Time

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 45.1 Quantum Field Theory on Curved Space-Time (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 45.2 Quantum Field Theory on Curved Space-Time (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: From harmonic oscillators to classical fields, quantization of fields, particles in curved space-time, quantum fields in expanding universe, Quantum fields in de Sitter space, accelerated observer and Unruh effect, Hawking effect, Casimir effect, path integral and effective action, heat kernel method, vacuum polarization and renormalization, conformal anomaly.

Learning outcomes	The module aims to convey familiarity with the basic concepts of quantum effects in an external gravitational field and familiarity with the most important concepts of quantum field theory.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Viatcheslav Mukhanov
Language(s)	English
Additional information	None

Module: WP 46 Symplectic Geometry I

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 46.1 Symplectic Geometry 1 (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 46.2 Symplectic Geometry 1 (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Mathematik
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module deals with symplectic and Poisson manifolds, Hamiltonian systems, symmetries und moment map, symplectic reduction, integrable systems, toric manifolds, Duistermaat-Heckmann theorem.
Learning outcomes	The main goals of this module are the understanding of the mathematical structures arising in classical mechanics, both from the physical and mathematical perspective, and the foundations of modern symplectic geometry.
Type of examination	Written exam or oral examination

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dieter Kotschick, PhD
Language(s)	English
Additional information	None

Module: WP 47 Conformal Field Theory

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 47.1 Conformal Field Theory (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 47.2 Conformal Field Theory (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module deals with Conformal Field Theory in two dimensions, a perfect pedagogical example of Mathematical Physics with applications in String Theory and Statistical Physics. It starts with the basics, which is the underlying Virasoro algebra, its representation theory and the basic notions in CFT like the operator product expansion, fusion rules, Kac-Moody and chiral algebras. Putting the CFT on a torus reveals non-chiral aspects of CFT like partition functions, its modular properties and the Verlinde formula. Basic notions of supersymmetric CFTs are also discussed,

	like the chiral ring and the spectral flow which are important for string theoretic applications. The final topic is Boundary CFT which includes the introduction of boundary states and the Cardy formula.
Learning outcomes	The main goal of this module is to make the students aquainted with a prime example of Mathematical physics which beautifully combines the physics of quantum field theory (QFT) with advanced mathematical structures, in effect making the theory exactly solvable and going way beyond the usual perturbative approach to QFT. Moreover, it complements the parallel course on String Theory I.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 48 Stochastic Processes in Physics and Biology

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 48.1 Stochastic Processes in Physics and Biology (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 48.2 Stochastic Processes in Physics and Biology (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the following topics: Markov chains and population genetics, branching processes, continuous time Markov processes and molecular motors, gene regulation, rate equations, Master equation and Fokker-Planck equation, Kramers-Moyal expansion, Smoluchowski equation, phase separation kinetics, Langevin equations and non-equilibrium growth processes, diffusion limited aggregation, directed percolation, diffusion-reaction models, linear

	response theory, Onsager relations, mode-coupling theory and glass transition.
Learning outcomes	The module aims to convey fundamental abilities in modeling and analyzing complex biological systems, using the methods of physics.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Erwin Frey
Language(s)	English
Additional information	None

Module: WP 49 Stochastic Processes

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 49.1 Stochastic Processes (Lecture)	WiSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 49.2 Stochastic Processes (Exercise Course)	WiSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	MSc Mathematik
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	The module covers the mathematical description and analysis of complex random phenomena. In particular, it discusses the following topics: Weak convergence, compactness criteria, Markov processes: recurrence and transience, harmonic functions, stationary processes, ergodic theorem for Markov chains, stochastic processes in continuous time: renewal processes, Poisson process, Levy processes, Brownian motion, Donsker's invariance principle, Martingales and stopping times in continuous time,

	stochastic integral with Brownian motion as integrator, Ito formula.
Learning outcomes	Students learn to construct mathematical models and to analyze complex random phenomena, especially with time dependencies.
Type of examination	Written exam or oral examination
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Franz Merkl
Language(s)	English
Additional information	None

Module: WP 50 Current Research Topics in Advanced and Applied Quantum Mechanics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 50.1 Current Research Topics in Advanced and Applied Quantum Mechanics 2 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 50.2 Current Research Topics in Advanced and Applied Quantum Mechanics 2 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fied of advanced and applied quantum mechanics.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of advanced and applied quantum mechanics.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Jan von Deft
Language(s)	English
Additional information	None

Module: WP 51 Current Research Topics in Quantum Field Theory and Gauge Theories II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 51.1 Current Research Topics in Quantum Field Theory and Gauge Theories 2 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 51.2 Current Research Topics in Quantum Field Theory and Gauge Theories 2 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fied of Quantum Field Theory and Gauge Theories.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Quantum Field Theory and Gauge Theories.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Georgi Dvali
Language(s)	English
Additional information	None

Module: WP 52 Current Research Topics in Cosmology, General Relativity, and Differential Geometry II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 52.1 Current Research Topics in Cosmology, General Relativity, and Differential Geometry 2 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 52.2 Current Research Topics in Cosmology, General Relativity, and Differential Geometry 2 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fied of Cosmology, General Relativity, and Differential Geometry.

Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Cosmology, General Relativity, and Differential Geometry.
Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Viatcheslav Mukhanov
Language(s)	English
Additional information	None

Module: WP 53 Current Research Topics in String Theory and Geometry II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 53.1 Current Research Topics in String Theory and Geometry 2 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 53.2 Current Research Topics in String Theory and Geometry 2 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of String Theory and Geometry.
Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of String Theory and Geometry.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Dieter Lüst
Language(s)	English
Additional information	None

Module: WP 54 Current Research Topics in Statistical Physics and Stochastics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 54.1 Current Research Topics in Statistical Physics and Stochastics 2 (Lecture)	WiSe and SoSe	60 h (4 SWS)	120 h	(6)
Exercise course	WP 54.2 Current Research Topics in Statistical Physics and Stochastics 2 (Exercise Course)	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 9 ECTS credits have to be acquired. Class attendance averages about 6 contact hours. Including time for self-study, 270 hours have to be invested.

Module type	Complusory elective module with mandatory courses
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	This module treats current research topics in the fields of Statistical Physics and Stochastics.
Learning outcomes	The module aims to convey advanced methods and knowledge in a selected area of Statistical Physics and Stochastics.

Type of examination	Written exam or oral examination or term paper
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Prof. Dr. Erwin Frey
Language(s)	English
Additional information	None

Module: WP 55 Advanced Course on Selected Topics in Theoretical and Mathematical Physics II

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Seminar	WP 55.1 Seminar on Selected Topics in Theoretical and Mathematical Physics 2	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 2 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected special topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	This module provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Presentation

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 56 Selected Topics in Theoretical and Mathematical Physics III

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 56.1 Lecture on Selected Topics in Theoretical and Mathematical Physics 3	WiSe and SoSe	30 h (2 SWS)	60 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 2 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	MSc Physics
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected special topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	This module provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 57 Block Lecture on Selected Topics in Theoretical and Mathematical Physics III

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 57.1 Block Lecture on Selected Topics in Theoretical and Mathematical Physics 3	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected topics in theoretical and mathematical physics are presented in a compact format. Special attention is paid to recent developments in research.
Learning outcomes	This module provides an in-depth discussion of a specific topic aiming to make contact with ongoing research.
Type of examination	Written exam or oral examination or term paper

Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: WP 58 Summer School on Selected Topics in Theoretical and Mathematical Physics III

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Lecture	WP 58.1 Summer School on Selected Topics in Theoretical and Mathematical Physics 3	WiSe and SoSe	-	90 h	(3)

For successful completion of the module, 3 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 90 hours have to be invested.

Module type	Complusory elective module with mandatory course
Usability of the module in other programmes	None
Elective guidelines	The module can be selected in compliance with the following rules: From the compulsory elective modules WP 1 to WP 58, compulsory elective modules with a total of 69 ECTS credits must be selected. At least two compulsory elective modules must be selected from the compulsory elective modules WP 1 to WP 3 and WP 17. In the 1st semester compulsory elective modules with a total of 24 ECTS credits are to be selected, in the 2nd semester compulsory elective modules with a total of 30 ECTS credits and in the 3rd semester compulsory elective modules with a total of 15 ECTS credits.
Entry requirements	None
Semester	Recommended semester: 3
Duration	The successful completion of the module takes 1 semester.
Content	In this module, selected topics in theoretical and mathematical physics are presented. Special attention is paid to recent developments in research.
Learning outcomes	Schools serve to broaden the scientific view by an intense treatment of a wide spectrum of topics in a limited amount of time.

Type of examination	Written exam or oral examination or term paper or scientific protocol or presentation or poster
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator
Language(s)	English
Additional information	None

Module: P 3 Final Module

Programme	Master's Programme: Theoretical and Mathematical Physics (Master of Science, M.Sc.)

Related module parts

Course type	Course (mandatory)	Rotation	Contact hours	Self-study hours	ECTS
Master's thesis	P 3.1 Master's Thesis	WiSe and SoSe	-	750 h	(25)
Disputation	P 3.2 Disputation	WiSe and SoSe	-	150 h	(5)

For successful completion of the module, 30 ECTS credits have to be acquired. Class attendance averages about 0 contact hours. Including time for self-study, 900 hours have to be invested.

Module type	Mandatory module
Usability of the module in other programmes	None
Elective guidelines	None
Entry requirements	None
Semester	Recommended semester: 4
Duration	The successful completion of the module takes 1 semester.
Content	In the master thesis, selected and recent topics of theoretical and mathematical physics a researched autonomously and written up in a concise way.
Learning outcomes	In the master thesis, the student demonstrates to be able to in depth analyse a research problem in his or her subject autonomously using scientific methods in a limited amount of time.
Type of examination	Master's thesis and disputation
Type of assessment	The successful completion of the module will be graded.
Requirements for the gain of ECTS credits	ECTS credits will be granted when the module examination (or the examination of pertinent mandatory and potential elective compulsary module parts) has/have been completed successfully.
Responsible contact	Program Coordinator

Language(s)	English
Additional information	None