Module Catalogue
for the Subject
Mathematical Physics
as a Master’s with 1 major
with the degree "Master of Science"
(120 ECTS credits)

Examination regulations version: 2020
Responsible: Faculty of Mathematics and Computer Science
Responsible: Faculty of Physics and Astronomy
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Module Catalogue for the Subject
Mathematical Physics
Master's with 1 major, 120 ECTS credits

Module Group Current Topics
Current Topics of Mathematical Physics
Current Topics of Mathematical Physics
Current Topics of Mathematical Physics
Current Topics of Mathematical Physics

Subfield Research in Groups
Research in Groups - Algebra
Research in Groups - Discrete Mathematics
Research in Groups - Dynamical Systems and Control Theory
Research in Groups - Complex Analysis
Research in Groups - Geometry and Topology
Research in Groups - Mathematics in Context
Research in Groups - Mathematics in the Sciences
Research in Groups - Measure and Integral
Research in Groups - Numerical Mathematics and Applied Analysis
Research in Groups - Robotics, Optimization and Control Theory
Research in Groups - Time Series Analysis
Research in Groups - Statistics
Research in Groups - Number Theory
Research in Groups - Control Theory of Quantum Mechanical Systems
Research in Groups - Differential Geometry
Research in Groups - Deformation Quantization
Research in Groups - Non-linear Analysis
Research in Groups - Operator Algebras
Research in Groups - Lie Theory
Research in Groups - Applied Differential Geometry
Research in Groups - Mathematical Physics
Study Group Modern Differential Geometry
Study Group Symplectic and Poisson Geometry
Study Group Operator Algebras and Representation Theory
Study Group Hopf Algebras
Study Group Conformal Field Theorie
Study Group Statistical Mechanics
Study Group Quantum Field Theory
Study Group Riemannian Geometry
Study Group Mathematical Physics

Thesis
Professional Specialization Mathematical Physics
Scientific Methods and Project Management Mathematical Physics
Master Thesis Mathematical Physics
### The subject is divided into

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<th>ECTS credits</th>
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Learning Outcomes

German contents and learning outcome available but not translated yet.

Wissenschaftliche Befähigung

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, sich selbständig mithilfe von, auch fremdsprachiger, Fachliteratur in aktuelle Forschungsgebiete der Mathematischen Physik einzuarbeiten.
- Die Absolventinnen und Absolventen sind in der Lage, ihre Kenntnisse, Ideen und Problemlösungen zu komplexen Sachverhalten einem Fachpublikum gegenüber verständlich zu präsentieren.
- Die Absolventinnen und Absolventen besitzen vertiefte Kenntnisse der mathematischen Grundlagen der klassischen und Quantenphysik.
- Die Absolventinnen und Absolventen besitzen die für selbstständiges wissenschaftliches Arbeiten, insbesondere für ein Promotionsstudium erforderlichen Fach- und Methodenkenntnisse, sowie Denk- und Arbeitsweisen.
- Die Absolventinnen und Absolventen kennen die Regeln guter wissenschaftlicher Praxis und sind in der Lage, sie bei umfangreichen Arbeiten zu beachten.
- Die Absolventinnen und Absolventen besitzen weiterführende Kenntnisse aktueller Gebiete der Mathematischen Physik und können sicher mit fortgeschrittenen Methoden dieser Gebiete umgehen.
- Die Absolventinnen und Absolventen besitzen vertiefte Kenntnisse und Überblick über die aktuelle Forschung in mindestens einem Teilgebiet der Mathematischen Physik.
- Die Absolventinnen und Absolventen sind in der Lage, mit internationalen Fachvertretern und -vertreterinnen auf dem aktuellen Stand der Forschung Fragestellungen der Mathematischen Physik zu diskutieren.
- Die Absolventinnen und Absolventen kennen angrenzende Gebiete der Mathematik und Physik, und erkennen interdisziplinäre Zusammenhänge.

Befähigung zur Aufnahme einer Erwerbstätigkeit

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, ihre Kenntnisse, Ideen und Problemlösungen zielgruppenorientiert verständlich zu formulieren und zu präsentieren.
- Die Absolventinnen und Absolventen sind in der Lage, komplexe Probleme aus anderen Gebieten zu erkennen, strukturieren und modellieren, mit mathematischen und physikalischen Methoden Lösungswege zu entwickeln und diese Ergebnisse zu interpretieren und bewerten.
- Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
- Die Absolventinnen und Absolventen sind in der Lage, konstruktiv und zielorientiert in internationalen, interdisziplinär zusammengesetzten Teams zu arbeiten und hierbei Verantwortung zu tragen.
- Die Absolventinnen und Absolventen sind in der Lage, sich neue Wissensgebiete und aktuelle Entwicklungen selbständig, effizient und systematisch zu erschließen.
- Die Absolventinnen und Absolventen sind in der Lage, auch bei unvollständig vorliegenden Informationen mathematisch-physikalische Probleme wissenschaftlich und unter Beachtung der
Regeln guter wissenschaftlicher Praxis selbstständig zu bearbeiten und die Ergebnisse und Folgen ihrer Arbeit darzustellen, zu bewerten und zu vertreten.

**Persönlichkeitsentwicklung**

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, in partizipativen Prozessen gestaltend mitzuwirken.
- Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
- Die Absolventinnen und Absolventen sind in der Lage, komplexe Ideen und Lösungsvorschläge allgemeinverständlich zu formulieren und professionell zu präsentieren.
Abbreviations used

Course types: E = field trip, K = colloquium, O = conversatorium, P = placement/lab course, R = project, S = seminar, T = tutorial, Ü = exercise, V = lecture

Term: SS = summer semester, WS = winter semester

Methods of grading: NUM = numerical grade, B/NB = (not) successfully completed

Regulations: (L)ASPO = general academic and examination regulations (for teaching-degree programmes), FSB = subject-specific provisions, SFB = list of modules

Other: A = thesis, LV = course(s), PL = assessment(s), TN = participants, VL = prerequisite(s)

Conventions

Unless otherwise stated, courses and assessments will be held in German, assessments will be offered every semester and modules are not creditable for bonus.

Notes

Should there be the option to choose between several methods of assessment, the lecturer will agree with the module coordinator on the method of assessment to be used in the current semester by two weeks after the start of the course at the latest and will communicate this in the customary manner.

Should the module comprise more than one graded assessment, all assessments will be equally weighted, unless otherwise stated below.

Should the assessment comprise several individual assessments, successful completion of the module will require successful completion of all individual assessments.

In accordance with

the general regulations governing the degree subject described in this module catalogue:

ASPO2015

associated official publications (FSB (subject-specific provisions)/SFB (list of modules)):

22-Jan-2020 (2020-7)

??-??-2022 (2022-??)

This module handbook seeks to render, as accurately as possible, the data that is of statutory relevance according to the examination regulations of the degree subject. However, only the FSB (subject-specific provisions) and SFB (list of modules) in their officially published versions shall be legally binding. In the case of doubt, the provisions on, in particular, module assessments specified in the FSB/SFB shall prevail.
Compulsory Courses

(20 ECTS credits)
<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Analysis and Geometry of Classical Systems</td>
<td>10-M=MP1-161-m01</td>
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<table>
<thead>
<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
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<tbody>
<tr>
<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<thead>
<tr>
<th>ECTS</th>
<th>Method of grading</th>
<th>Only after succ. compl. of module(s)</th>
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<tbody>
<tr>
<td>10</td>
<td>numerical grade</td>
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<thead>
<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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**Contents**

Modern analytic methods (such as partial differential equations) and geometric methods (such as differential geometry) for the description of classical physics. Examples include movements of deformable bodies as reaction to outer load (deformation of elastic bodies, flow of a fluid, stream of a gas). Additional examples include geometric mechanics and symplectic geometry, classical field theory and classical gauge theory, general relativity theory.

**Intended learning outcomes**

The student gains insight into modern methods in mathematics, which are applied in classical physics. He/She masters advanced techniques in this field and is able to apply them to complex problems.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)  
Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Language of assessment: German or English

creditable for bonus

**Allocation of places**

--

**Additional information**

--

**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject
Mathematical Physics
Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<td>10-M=MP2-161-m01</td>
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</table>

### Contents
Modern algebraic methods for dynamics of quantum systems, e.g., operator algebras with applications in algebraic quantum field theory, spectral theory, symmetries and representation theory.

### Intended learning outcomes
The student gains insight into modern methods in mathematics, which are applied in quantum physics. He/She masters advanced techniques in this field and is able to apply them to complex problems.

### Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Language of assessment: German or English
creditable for bonus

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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Compulsory Electives
(50 ECTS credits)
Subfield Mathematics
(min. 8 ECTS credits)
### Module Catalogue for the Subject
Mathematical Physics
Master's with 1 major, 120 ECTS credits

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<th>Module title</th>
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<td>Applied Analysis</td>
<td>10-M=AAAN-161-m01</td>
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</tbody>
</table>

### Contents

### Intended learning outcomes
The student is acquainted with the fundamental notions, methods and results of higher analysis. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics and other natural and engineering sciences.

### Courses
(type, number of weekly contact hours, language — if other than German)

- V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

### Allocation of places
--

### Additional information
--

**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
### Module title
Topics in Algebra

### Abbreviation
10-M=AALG-161-m01

### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
10

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
Contemporary topics in algebra, for example coding theory, elliptic curves, algebraic combinatorics or computer algebra.

### Intended learning outcomes
The student is acquainted with fundamental concepts and methods in a contemporary field of algebra, and is able to apply these skills to complex questions.

### Courses
(type, number of weekly contact hours, language — if other than German)

- **V (4) + Ü (2)**

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

### Allocation of places
--

### Additional information
--

### Referred to in LPO I
( examination regulations for teaching-degree programmes)

--
Module title | Abbreviation
---|---
Differential Geometry | 10-M=ADGM-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
10 | numerical grade | --

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | --

Contents
Central and advanced results in differential geometry, in particular about differentiable and Riemannian manifolds.

Intended learning outcomes
The student is acquainted with concepts and methods for differentiable manifolds or Riemannian manifolds, is able to apply these methods and knows about the interaction of local and global methods in differential geometry.

Courses
(type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

Allocation of places
--

Additional information
--

Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Module title | Complex Analysis
---|---
Abbreviation | 10-M=AFTH-161-m01

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

ECTS | 10 | Method of grading | numerical grade |
---|---|---|---|
Duration | 1 semester | Module level | graduate |
Other prerequisites | -- |

Contents
In-depth study of mapping properties of analytic functions and their generalisations with modern analytic and geometric methods. Structural properties of families of holomorphic and meromorphic functions. Special functions (e.g. elliptic functions).

Intended learning outcomes
The student is acquainted with the fundamental notions, methods and results of higher complex analysis, in particular the (geometric) mapping properties of holomorphic functions. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

Courses
V (4) + Ü (2)
Module taught in: German and/or English

Method of assessment
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

Allocation of places
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Additional information
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Referred to in LPO I
(examination regulations for teaching-degree programmes)
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<tr>
<td>Geometric Structures</td>
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<td>graduate</td>
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</table>

**Contents**

Tits buildings, generalised polygons or related geometric structures, automorphisms, BN pairs in groups, Moufang conditions, classification results.

**Intended learning outcomes**

The student is acquainted with the fundamental notions, methods and results concerning a type of geometric structure. He/She is able to establish a connection between these results and broader theories, and learns about the interactions of geometry and other fields of mathematics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

**Allocation of places**

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**Additional information**

--

**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
## Module title

Industrial Statistics 1

## Abbreviation

10-M=AIST-161-m01

## Module coordinator

Dean of Studies Mathematik (Mathematics)

## Module offered by

Institute of Mathematics

## ECTS

10

## Method of grading

numerical grade

## Only after succ. compl. of module(s)

--

## Duration

1 semester

## Module level

graduate

## Other prerequisites

--

## Contents

Theory of parameter and domain estimates, tests for statistical estimates, distribution models, empirical distribution analysis, comparative analysis, statistical product testing, survey sampling, audit sampling.

## Intended learning outcomes

The student masters the fundamental statistical methods for industrial applications.

## Courses

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of weekly contact hours</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>4</td>
<td>German and/or English</td>
</tr>
<tr>
<td>Ü</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Module taught in: German and/or English

## Method of assessment

(a) written examination (approx. 90 to 120 minutes, usually chosen) or (b) oral examination of one candidate each (approx. 20 minutes) or (c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

## Allocation of places

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## Additional information

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## Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Lie Theory</td>
<td>10-M=ALTH-161-m01</td>
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<tr>
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<tr>
<td>1 semester</td>
<td>graduate</td>
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</table>

**Contents**

Linear Lie groups and their Lie algebras, exponential function, structure and classification of Lie algebras, classic examples, applications, e.g. in physics and control theory.

**Intended learning outcomes**

The student is acquainted with the fundamental results, theorems and methods in Lie theory. He/She is able to apply these to common problems, and knows about the interactions of group theory, analysis, topology and linear algebra.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes, usually chosen) or
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- c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
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<tr>
<td>Numeric of Large Systems of Equations</td>
<td>10-M=ANGG-161-m01</td>
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</table>

**Contents**

Discretisation of elliptic differential equations, classical iteration methods, preconditioners, multigrid methods.

**Intended learning outcomes**

The student is acquainted with the most important methods for solving large systems of equations, and knows the most efficient way to solve a given system of equations.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

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<td>Basics in Optimization</td>
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### Contents
Fundamental methods and techniques in continuous optimization, unrestricted optimization, conditions for optimality, restricted optimization, examples and applications in natural and engineering sciences as well as economics.

### Intended learning outcomes
The student knows the fundamental methods of continuous optimization, can judge their strengths and weaknesses and can decide which method is the most suitable in applications.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

### Allocation of places
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</table>

**Contents**

Introduction to mathematical systems theory: stability, controllability and observability, state feedback and stability, basics in optimal control.

**Intended learning outcomes**

The student is acquainted with the fundamental notions and methods of control theory. He/She is able to establish a connection between these results and broader theories, and learns about the interactions of geometry and other fields of mathematics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

**Stochastic Models of Risk Management**

### Abbreviation

10-M=ASMR-161-m01

### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

### ECTS

10

### Method of grading

Only after succ. compl. of module(s)

### Duration

1 semester

### Module level

graduate

### Other prerequisites

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### Contents

Measure theory, risk diagrams, failure mode and effects analysis, risk assessment in auditing, shortfall measures, value at risk, conditional value at risk, axiomatic of risk measures, modelling of interdependencies, copula, modelling of functional interrelations, regression models, basics in time series modelling, aggregated losses, estimates of shortfall measures, estimates of value at risk and conditional value at risk, basics in empirical time series analysis, methods of exponential smoothing, predictions and prediction domains, estimates of value at risk in time series, elementary empirical regression analysis, simulation methods.

### Intended learning outcomes

The student is acquainted with the fundamental methods of stochastic risk analysis.

### Courses

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Module taught in: German and/or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

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### Additional information

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<td>Stochastical Processes</td>
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</table>

**Contents**

Markov chains, queues, stochastic processes in C[0,1], Brownian motion, Donsker's theorem, projective limits.

**Intended learning outcomes**

The student is acquainted with the fundamental notions and methods of stochastical processes and can apply them to practical problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English

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**Allocation of places**

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<tr>
<td>Topology</td>
<td>10-M-ATOP-161-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

**ECTS** | **Method of grading** | **Only after succ. compl. of module(s)** |
---|---|---|
10 | numerical grade | -- |

**Duration** | **Module level** | **Other prerequisites** |
---|---|---|
1 semester | graduate | -- |

**Contents**
Set-theoretic topology, topological invariants (e.g. fundamental group, connection), construction of topological spaces, covering spaces.

**Intended learning outcomes**
The student is acquainted with the fundamental results, theorems and methods in topology and is able to apply these to common problems.

**Courses**
V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment**
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
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**Additional information**
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(examination regulations for teaching-degree programmes)
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</table>

### Contents
Additive model, linear filters, autocorrelation, moving average, autoregressive processes, Box-Jenkins method.

### Intended learning outcomes
The student is acquainted with the fundamental methods of time series analysis and can apply them to practical problems.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

### Allocation of places
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(examination regulations for teaching-degree programmes)

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## Module Catalogue for the Subject Mathematical Physics

### Master's with 1 major, 120 ECTS credits

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<tr>
<th>Module title</th>
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<tbody>
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<td>Number Theory</td>
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</table>

## Contents

Number-theoretic functions and their associated Dirichlet series resp. Euler products, their analytic theory with applications to prime number distribution and diophantine equations; discussion of the Riemann hypothesis, overview of the development of modern number theory.

## Intended learning outcomes

The student is acquainted with the fundamental methods of analytics number theory, can deal with algebraic structures in number theory and knows methods for the solution of diophantine equations. He/She has insight into modern developments in number theory.

## Courses

<table>
<thead>
<tr>
<th>Type, number of weekly contact hours, language — if other than German</th>
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## Method of assessment

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## Allocation of places

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## Additional information

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## Referred to in LPO I (examination regulations for teaching-degree programmes)

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## Module title
Giovanni Prodi Lecture (Master)

## Abbreviation
10-M=AGPCin-152-m01

## Module coordinator
Dean of Studies Mathematik (Mathematics)

## Module offered by
Institute of Mathematics

## ECTS
5

## Method of grading
numerical grade

## Duration
1 semester

## Module level
graduate

## Other prerequisites
--

## Contents
Introduction to a specialised topic in mathematics by an international expert.

## Intended learning outcomes
The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

## Courses
V (3) + Ü (1)

Module taught in: English

## Method of assessment
(a) written examination (approx. 60 to 90 minutes, usually chosen) or (b) oral examination of one candidate each (approx. 15 minutes) or (c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: English

creditable for bonus

## Allocation of places
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## Additional information
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<table>
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<td>Selected Topics in Analysis</td>
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**Contents**

In-depth discussion of a specialised topic in analysis taking into account recent developments and interrelations with other mathematical concepts.

**Intended learning outcomes**

The student is acquainted with advanced results in a selected topic in analysis, and is able to apply these to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)  
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester  
Language of assessment: German or English  
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject
#### Mathematical Physics

**Master’s with 1 major, 120 ECTS credits**

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<td>Algebraic Topology</td>
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**Contents**

Homology, homotopy invariance, exact sequences, cohomology, application to the topology of Euclidean spaces.

**Intended learning outcomes**

The student is acquainted with advanced results in algebraic topology.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)  
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)  
Assessment offered: In the semester in which the course is offered and in the subsequent semester  
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**Allocation of places**

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**Additional information**

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<table>
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<td>Groups and their Representations</td>
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**Module coordinator**

Dean of Studies Mathematik (Mathematics)

**Module offered by**

Institute of Mathematics

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**Contents**

Finite permutation groups and character theory of finite groups, interrelations and special techniques such as the S-rings of Schur.

**Intended learning outcomes**

The student masters advanced algebraic concepts and methods. He/She gains the ability to work on contemporary research questions in group theory and representation theory and can apply his/her skills to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents

The module builds on the topics covered in module 10-M=ADGM and discusses these in more detail: symplectic geometry, cotangent bundles and other examples of symplectic manifolds, symmetries and Noether theorem, phase space reduction, normal forms, introduction to Poisson geometry.

### Intended learning outcomes

The student is acquainted with selected advanced applications of differential geometry to geometric mechanics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

### Courses

- V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment

- a) written examination (approx. 90 to 120 minutes, usually chosen) or
- b) oral examination of one candidate each (approx. 20 minutes) or
c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

### Allocation of places

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**Contents**

Linear models, regression analysis, nonlinear regression, experimental design, basics in time series modelling, basics in empirical time series analysis, methods of exponential smoothing, predictions and prediction domains, statistical process monitoring.

**Intended learning outcomes**

The student masters advanced statistical methods for industrial applications.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

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**Contents**

Combination of Galois theory, group theory and the theory of function fields with the aim of application in number theory, e.g. topics around Hilbert's irreducibility theorem, permutation polynomials (e.g. Calitz-Wan-conjecture) and the inverse problem in Galois theory.

**Intended learning outcomes**

The student masters advanced algebraic concepts and methods. He/She gains the ability to work on contemporary research questions in algebra and can apply his/her skills to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Contents**

Types of partial differential equations, qualitative properties, finite differences, finite elements, error estimates (numerical methods for elliptic, parabolic and hyperbolic partial differential equations; finite elements method, discontinuous Gelerkin finite elements method, finite differences and finite volume methods).

**Intended learning outcomes**

The student is acquainted with advanced methods for discretising partial differential equations.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Contents**

Selected topics in optimization, e.g. inner point methods, semidefinite programs, non-smooth optimization, game theory, optimization with differential equations.

**Intended learning outcomes**

The student is acquainted with advanced methods in continuous optimization. He gains the ability to work on contemporary research questions in continuous optimization.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English
creditable for bonus

**Allocation of places**

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**Contents**

Contingency tables, categorical regression, one-factorial variance analysis, two-factorial variance analysis, discriminant function analysis, cluster analysis, principal component analysis, factor analysis.

**Intended learning outcomes**

The student is acquainted with the fundamental methods in statistical analysis and can apply them to practical problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

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**Module coordinator**
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**Module offered by**
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**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
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**Contents**
State-space models, Kalman filter, frequency spaces, Fourier analysis, periodograms, characterisation of autocovariance functions.

**Intended learning outcomes**
The student is acquainted with advanced methods in time series analysis. He gains the ability to work on contemporary research questions in this field.

**Courses**
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment**
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Language of assessment: German or English
creditable for bonus

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**Contents**

Advanced methods and results in a selected field of discrete mathematics (e.g. coding theory, cryptography, graph theory or combinatorics)

**Intended learning outcomes**

The student is acquainted with advanced results in a selected topic in discrete mathematics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

Creditable for bonus: --

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**Contents**

Fundamentals of dynamical systems, e.g. stability theory, ergodic theory, Hamiltonian systems.

**Intended learning outcomes**

The student masters the mathematical methods in the theory of dynamic systems, and is able to analyse their quality.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English
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**Contents**

In-depth discussion of a special type of geometry taking into account recent developments and interrelations with other mathematical structures, e.g. topological geometries, diagram geometries.

**Intended learning outcomes**

The student is acquainted with advanced results in a selected field of geometry and can apply his/her skills to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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### Contents

Partial differential equations and/or variational methods in the context of continuum mechanics.

### Intended learning outcomes

The student masters the mathematical methods in mathematical continuum mechanics and knows about their main fields of application.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<tr>
<td>Mathematical Imaging</td>
<td>10-M=VMBV-161-m01</td>
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### Contents

Mathematical fundamentals of image processing and computer vision such as elementary projective geometry, camera models and camera calibration, rigid and non-rigid registration, reconstruction of 3D objects from camera pictures; algorithms; module might also include an introduction to geometric methods and tomography.

### Intended learning outcomes

The student masters the mathematical methods in the theory of image processing and knows about their main fields of application.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

credible for bonus

### Allocation of places

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### Additional information

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<td>Selected Topics in Mathematical Physics</td>
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### Contents

Selected topics in mathematical physics, for example continuum mechanics, fluid dynamics, mathematical material sciences, geometric field theory, advanced topics in quantum theory.

### Intended learning outcomes

The student is acquainted with an advanced topic in mathematical physics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

### Courses

- **V (4) + Ü (2)**
  - Module taught in: German and/or English

### Method of assessment

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

### Allocation of places

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### Additional information

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### Contents
Selected topics in linear and non-linear control theory, e. g. networked linear control systems, controllability of bilinear systems.

### Intended learning outcomes
The student gains insight into contemporary research problems in control theory. He/She masters advanced techniques in this field and can apply them to complex problems.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

### Allocation of places
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### Additional information
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<td>Inverse Problems</td>
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**Module coordinator**

Dean of Studies Mathematik (Mathematics)

**Module offered by**

Institute of Mathematics

**ECTS** | **Method of grading** | **Only after succ. compl. of module(s)** |
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**Contents**

Linear operator equations, ill-posed problems, regularisation theory, Tikhonov regularisation, iterative regularisation methods, examples of ill-posed problems.

**Intended learning outcomes**

The student can judge whether a given problem is well posed or ill posed. He/She can apply regularisation methods and examine them regarding stability and convergence, and is familiar with selected inverse problems.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Contents**

Basics in module theory: modules and module spaces, canonical decomposition and representations, simple, semi-simple and complex modules, module trees and their defibrations, distorsion theorems, reduction theorems.

**Intended learning outcomes**

The student masters mathematical methods in module theory and is able to analyse their quality.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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<tbody>
<tr>
<td>Methods in nonlinear analysis (e.g. topological methods, monotony and variational methods) with applications.</td>
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<tr>
<td>The student is acquainted with the concepts of non-linear analysis, can compare them and assess their applicability on practical problems.</td>
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<td>Optimal Control</td>
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### Contents
Basics in optimal control of ordinary and partial differential equations, theory of optimal control, conditions for optimality, methods for numerical solution.

### Intended learning outcomes
The student is acquainted with advanced methods in optimal control. He gains the ability to work on contemporary research questions in continuous optimization.

### Courses
(V (3) + Ü (1))
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German)

- a) written examination (approx. 60 to 90 minutes, usually chosen) or
- b) oral examination of one candidate each (approx. 15 minutes) or
- c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)
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Module title

Networked Systems

Abbreviation

10-M-VVSY-161-m01

Module coordinator

Dean of Studies Mathematik (Mathematics)

Module offered by

Institute of Mathematics

ECTS

5

Method of grading

numerical grade

Only after succ. compl. of module(s)

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Duration

1 semester

Module level

graduate

Other prerequisites

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Contents

Contemporary topics in networked linear and non-linear dynamical systems (homogenous and non-homogenous systems); analysis of control-theoretical aspects (controllability, accessibility, etc.).

Intended learning outcomes

The student is acquainted with advanced methods in the field of networked systems. He gains the ability to work on contemporary research questions in networked systems.

Courses (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

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Allocation of places

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Additional information

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**Contents**

The module builds on the topics covered in module 10-M=ADGM and discusses these in more detail: Wirtinger calculus, complex structures and complex manifolds, metrics on complex manifolds (e.g. conformal, hermitian, Kähler), differential operators on complex manifolds, classification of complex manifolds.

**Intended learning outcomes**

The student knows and masters advanced methods and notions in complex differential geometry. He is familiar with the central concepts in this field and is able to apply the fundamental proof methods independently.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

**Partial Differential Equations of Mathematical Physics**

### Abbreviation

10-M=VPDP-161-m01

### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

### ECTS

10

### Method of grading

numerical grade

### Only after succ. compl. of module(s)

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### Duration

1 semester

### Module level

graduate

### Other prerequisites

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### Contents

Elliptic, parabolic, and hyperbolic equations; Laplace equation, heat equation and wave equation as standard examples; initial and boundary value problems; well-posed and ill-posed problems; solution methods; extensions and generalisations; Hilbert space methods; Sobolev spaces and Fourier transforms.

### Intended learning outcomes

The student is acquainted with fundamental concepts and solution methods in the theory of partial differential equations, as well as standard examples from mathematical physics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

### Courses

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### Module taught in:

German and/or English

### Method of assessment

- a) written examination (approx. 90 to 120 minutes, usually chosen) or
- b) oral examination of one candidate each (approx. 20 minutes) or
- c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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## Module title

**Pseudo Riemannian and Riemannian Geometry**

### Abbreviation

10-M=VPRG-161-m01

## Module coordinator

Dean of Studies Mathematik (Mathematics)

## Module offered by

Institute of Mathematics

## ECTS

10

## Method of grading

Only after succ. compl. of module(s)

## Numerical grade

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## Duration

1 semester

## Module level

graduate

## Other prerequisites

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## Contents

The module builds on the topics covered in module 10-M=ADGM and discusses these in more detail: Riemannian and pseudo-Riemannian manifolds, Levi-Civita connection and curvature, geodesics and the exponential map, Jacobi fields, comparison theorems in Riemannian geometry, submanifolds, integration, d’Alembert and Laplace operators, causal structure of Lorenz manifolds, Einstein equations and applications in general relativity theory.

## Intended learning outcomes

The student is acquainted with advanced topics in differential geometry on Riemannian and pseudo-Riemannian manifolds. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

## Courses

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

## Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

## Allocation of places

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## Additional information

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## Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Module Title

**Functional Analysis**

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### Module Coordinator

Dean of Studies Mathematik (Mathematics)  
Institute of Mathematics

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### Duration

1 semester  
graduate  
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### Contents

Banach and Hilbert spaces, bounded operators, principles of functional analysis, further contemporary topics in functional analysis and applications to other fields of mathematics.

### Intended Learning Outcomes

The student is acquainted with fundamental concepts and methods in a contemporary field of functional analysis, and is able to apply these skills to complex questions.

### Courses

| (type, number of weekly contact hours, language — if other than German) |
| V (4) + Ü (2) |

Module taught in: German and/or English

### Method of assessment

(a) written examination (approx. 90 to 120 minutes, usually chosen) or  
(b) oral examination of one candidate each (approx. 20 minutes) or  
(c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English  
creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td><strong>Applied Differential Geometry</strong></td>
<td>10-M=VADG-161-m01</td>
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<td>Dean of Studies Mathematik (Mathematics)</td>
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<tbody>
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**Contents**

The module builds on the topics covered in module 10-M=ADGM and discusses selected applications of differential geometry, e.g. at the interface of control theory and mechanics (subriemannian geometry), in the smooth optimisation on manifolds or applications in physics.

**Intended learning outcomes**

The student is acquainted with selected advanced applications of differential geometry. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
- Assessment offered: In the semester in which the course is offered and in the subsequent semester
- Language of assessment: German or English
- creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module Title

**Giovanni Prodi Lecture Selected Topics (Master)**

### Abbreviation

10-M=VGPSin-152-m01

### Module Coordinator

Dean of Studies Mathematik (Mathematics)

### Module Offered by

Institute of Mathematics

### ECTS

10

### Method of Grading

Numerical grade

### Only after Succ. Compl. of Module(s)

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### Duration

1 semester

### Module Level

Graduate

### Other Prerequisites

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### Contents

Introduction to a specialised topic in mathematics by an international expert.

### Intended Learning Outcomes

The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

### Courses

(V (4) + Ü (2))

Module taught in: English

### Method of Assessment

(a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: English

Creditable for bonus

### Allocation of Places

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### Additional Information

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### Referred to in LPO I (Examination Regulations for Teaching-Degree Programmes)

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<tbody>
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**Contents**

Introduction to a specialised topic in mathematics by an international expert.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: English

creditable for bonus

**Allocation of places**

--

**Additional information**

--

**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

--
Module title | Abbreviation
---|---
Giovanni Prodi Lecture Modern Topics (Master) | 10-M=VGPMin-152-m01

Module coordinator | Module offered by
---|---
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
10 | numerical grade | --

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | --

Contents
Introduction to a specialised topic in mathematics by an international expert.

Intended learning outcomes
The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: English
creditable for bonus

Allocation of places
--

Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
## Module Catalogue for the Subject Mathematical Physics
### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
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<td>Geometric Complex Analysis</td>
<td>10-M=VGFT-192-m01</td>
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</tbody>
</table>

### Contents

Advanced methods and results in geometric complex analysis (e.g. conformal maps, conformal Riemannian metrics, quasiconformal maps, harmonic functions, biholomorphic maps).

### Intended learning outcomes

The student is acquainted with fundamental concepts, methods and results in geometric complex analysis, is able classify these results within more general theories and knows about the connections of geometric complex analysis with other fields of mathematics.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Language of assessment: German and/or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<table>
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<tr>
<td>Selected Topics in Numerical and Applied Mathematics</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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</tbody>
</table>

**Duration**
1 semester

**Module level**
grahuate

**Other prerequisites**
--

**Contents**
In-depth discussion of a specialised topic in numerical or applied mathematics taking into account recent developments and interrelations with other mathematical concepts.

**Intended learning outcomes**
The student is acquainted with advanced results in a selected topic in numerical or applied mathematics, and is able to apply these to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Language of assessment: German and/or English
Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

**Allocation of places**
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**Additional information**
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**Referred to in LPO I**
(examination regulations for teaching-degree programmes)

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### Cryptography/Coding Theory

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</tbody>
</table>

### Contents

Error detection and error correction, linear codes, channel coding theorems of Shannon, classical and contemporary codes, bounds, network codes, connections to cryptography.

### Intended learning outcomes

The student is acquainted with fundamental concepts, methods and results in coding theory and cryptography, is able to classify these results within more general theories and knows about the connections of coding theory and cryptography with other fields of mathematics.

### Courses

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<tr>
<th>Type</th>
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<td>German and/or English</td>
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<td>Ü</td>
<td>(2)</td>
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Module taught in: German and/or English

### Method of assessment

- a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Language of assessment: German and/or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

### Allocation of places

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### Additional information

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<td>Computer Algebra</td>
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**Module coordinator**  
Dean of Studies Mathematik (Mathematics)

**Module offered by**  
Institute of Mathematics

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</table>

**Duration**  
1 semester

**Module level**  
graduate

**Other prerequisites**  
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**Contents**
Fast multiplication of numbers, polynomials and matrices, fast chinese remainder theorem; factorisation of polynomials over finite fields; lattices, lattice basis reduction and LLL-algorithm; factorisation of rational polynomials, symbolic integration of rational functions; exact arithmetic with algebraic numbers; multivariate polynomials, Gröbner basis, Buchberger’s algorithm, algorithms for permutation groups.

**Intended learning outcomes**
The student knows about the theoretical foundations and the possible applications of several methods in computer algebra.

**Courses**
(type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Language of assessment: German and/or English
Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

**Allocation of places**  
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**Additional information**  
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<td>Algorithmic Number Theory</td>
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</table>

**Contents**

Binary numbers, computation of the greatest common divisor, pseudoprime tests, computation of primitive roots. Primality tests for Fermat and Mersenne numbers, factorisation methods (Pollard-Rho, (p-1)-method, elliptic curve method, quadratic sieve method), discrete logarithm.

**Intended learning outcomes**

The student knows about the theoretical foundations and the possible applications of several methods in algorithmic number theory.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Language of assessment: German and/or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

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<td>Algebraic Geometry</td>
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</table>

**Contents**

Affine and projective space, affine and projective varieties, morphisms and rational maps; function fields, divisors and Riemann-Roch theorem for curves; genus, singularities and Plücker formula; dual curve, dual surface; Bezout's theorem; Grassmann and flag varieties; 27 lines in a cubic surface.

**Intended learning outcomes**

The student is acquainted with fundamental concepts, methods and results in algebraic geometry, is able to classify these results within more general theories and knows about the connections of algebraic geometry with other fields of mathematics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)  
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)  
Language of assessment: German and/or English  
Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>Seminar in Algebra</td>
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**Module coordinator**

Dean of Studies Mathematik (Mathematics)

**Module offered by**

Institute of Mathematics

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</table>

**Duration**

1 semester

**Module level**

graduate

**Other prerequisites**

--

**Contents**

A modern topic in algebra.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>Seminar in Dynamical Systems and Control</td>
<td>10-M=SDSC-161-m01</td>
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**Contents**

A modern topic in dynamical systems and control.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

- S (2)
  - Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- talk (60 to 120 minutes)
  - Assessment offered: In the semester in which the course is offered and in the subsequent semester
  - Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

- --
Module title | Abbreviation
--- | ---
Seminar in Complex Analysis | 10-M=SCOA-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
--- | --- | ---
5 | numerical grade | --

Duration | Module level | Other prerequisites
1 semester | graduate | --

Contents
A modern topic in complex analysis.

Intended learning outcomes
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

Courses (type, number of weekly contact hours, language — if other than German)
S (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

Allocation of places
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Additional information
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**Contents**
A modern topic in applied differential geometry.

**Intended learning outcomes**
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)
S (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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Master's with 1 major Mathematical Physics (2020)
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<tbody>
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<td>1 semester</td>
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**Contents**

A modern topic in geometry and topology.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**
A modern topic in the research expertise of the current holder of the Giovanni Prodi Chair.

**Intended learning outcomes**
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

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**Module taught in:** English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

**talk (60 to 120 minutes)**
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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<td>Additional information</td>
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<td>1 semester</td>
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**Contents**

A modern topic in mathematics in the sciences.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
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**Contents**
A modern topic in numerical mathematics or applied analysis.

**Intended learning outcomes**
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

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<tr>
<th>Type</th>
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**Module taught in**: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- **talk (60 to 120 minutes)**
- **Assessment offered**: In the semester in which the course is offered and in the subsequent semester
- **Language of assessment**: German or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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**Contents**

A modern topic in optimisation.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

A modern topic in statistics.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

| S (2) | Module taught in: German and/or English |

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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**Allocation of places**

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**Additional information**

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**Contents**

A modern topic in non-linear analysis.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

A modern topic in applied mathematics.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (approx. 60 to 120 minutes)

Language of assessment: German or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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</table>

**Contents**

Supervising a tutorial or study group in the Bachelor's programme under guidance of the respective lecturer.

**Intended learning outcomes**

The student gains his/her first experience in teaching university mathematics. He/She knows basic didactical methods and can apply them in practical situations.

**Courses** (type, number of weekly contact hours, language — if other than German)

| Ü (2) |

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Assessment of tutoring activities by supervising lecturers or exercise supervisors (1 to 2 teaching units)

Language of assessment: German

**Allocation of places**

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**Additional information**

Application and selection with the teaching coordinator for mathematics

**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
Subfield Physics
(min. 8 ECTS credits)
Module Group General Theory of Physics

(ECTS credits)
Module title | Abbreviation
--- | ---
Quantum Mechanics II | 11-QM2-161-m01

Module coordinator | Module offered by
Managing Director of the Institute of Theoretical Physics and Astrophysics | Faculty of Physics and Astronomy

ECTS | Method of grading | Only after succ. compl. of module(s)
--- | --- | ---
8 | numerical grade | --

Duration | Module level | Other prerequisites
--- | --- | ---
1 semester | undergraduate | --

Contents

The contents of this lecture build upon and will be chosen in accordance with the topics of the Bachelor’s degree course "Quantum Mechanics I". Topics might include:

for QM:
1. Historical introduction
2. Single-particle states in a central potential
3. Principles of quantum mechanics
4. Spin and angular momentum
5. Approximations of energy eigenvalues
6. Approximations for time-dependent problems
7. Second quantisation
8. Potential scattering
9. General scattering theory
10. Canonical formalism
11. Charged particles in electromagnetic fields
12. Quantum theory of radiation
13. Quantum entanglement

Intended learning outcomes

The students acquire in-depth knowledge of advanced quantum mechanics. This knowledge is highly relevant to most of the theoretical Master's degree courses in Astrophysics, Particle Physics and Condensed Matter Physics. The completion of this course is highly recommended.

Courses (type, number of weekly contact hours, language — if other than German)

V (4) + R (2)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

If a written examination was chosen as method of assessment, this may be changed and assessment may instead take the form of an oral examination of one candidate each or an oral examination in groups. If the method of assessment is changed, the lecturer must inform students about this by four weeks prior to the original examination date at the latest.

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

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## Contents
1. Mathematical Foundations
2. Differential forms
3. Brief Summary of the special relativity
4. Elements of differential geometry
5. Electrodynamics as an example of a relativistic gauge theory
6. Field equations of the fundamental structure of general relativity
7. Stellar equilibrium and other astrophysical applications
8. Introduction to cosmology

## Intended learning outcomes
The students become familiar with the principal physical and mathematical concepts of general relativity. The main topics include modern formulation on the basis of differential forms. Furthermore, the similarities between electrodynamics as a gauge theory and general relativity are emphasised. The students learn to apply the theory to simple models of stellar equilibrium and are introduced to basic elements of cosmology.

## Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

## Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

## Allocation of places
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## Additional information
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## Referred to in LPO I
(examination regulations for teaching-degree programmes)
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<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Renormalization Group Methods in Field Theory</td>
<td>11-RMFT-161-m01</td>
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**Contents**

This course is complementary to the discussion of Wilson's renormalisation group (RG) as covered in the course "Renormalisation Group and Critical Phenomena" (11-CRP). It focuses on the diagrammatic formulation of RG flow equations and its relation to diagrammatic perturbation expansions. This is of particular relevance for interacting fermion systems in the context of functional renormalisation groups. An outline of the course might be:

1. Wilson’s RG
2. Path integrals of interacting fermions
3. Bethe-Salpeter equation
4. RG flow equations for the one-particle and two-particle vertex
5. Comparison of flow equations with diagrammatic resummation schemes (such as the random phase approximation)
6. RG flow equations for spin systems.

**Intended learning outcomes**

The students become familiar with the modern diagram-based description of many-particle systems. This knowledge serves as a theoretical basis for the examination of phenomena such as superconductivity, charge and spin density waves, and nematic instabilities.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + R (2)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes) or b) oral examination of one candidate each (approx. 30 minutes) or c) oral examination in groups (groups of 2, approx. 30 minutes per candidate) or d) project report (approx. 8 to 10 pages) or e) presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Module title | Abbreviation
---|---
Physics of Complex Systems | 11-PKS-161-m01

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**Contents**

1. Theory of critical phenomena in thermal equilibrium
2. Introduction into the physics out of equilibrium
3. Entropy production and fluctuation
4. Phase transitions away from equilibrium
5. Universality
6. Spin glasses
7. Theory of neural networks

**Intended learning outcomes**

The students acquire in-depth knowledge of a wide variety of concepts and methods essential for a thorough understanding of cooperative phenomena in complex many-particle systems. The main focus includes a thorough understanding of the concepts of entropy, entropy production and universality. The students are prepared for research activities in different areas of physics of complex systems.

**Courses**

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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<td>Advanced Theory of Quantum Computing and Quantum Information</td>
<td>11-QIC-201-m01</td>
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**Module coordinator**
Managing Director of the Institute of Theoretical Physics and Astrophysics

**Module offered by**
Faculty of Physics and Astronomy

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**Contents**
1. Brief summary of classical information theory
2. Quantum theory seen from the perspective of information theory
3. Composite systems and the Schmidt decomposition
4. Entanglement measures
5. Quantum operations, POVMs, and the theorems of Kraus and Stinespring
6. Quantum gates and quantum computers
7. Elements of the theory of decoherence

**Intended learning outcomes**
Comprehensive understanding of quantum states and identity matrix beyond the usual textbook interpretation. Knowledge of handling tensor products and dealing with quantum effects in multipartite quantum systems. In-depth understanding of the phenomenon of entanglement. Knowledge of the fundamental mathematical concepts of quantum information theory. Ability to assess the limitations of quantum computing arising from decoherence.

**Courses**
(type, number of weekly contact hours, language — if other than German)

V (3) + R (1)
Module taught in: German or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German and/or English
Assessment offered: In the semester in which the course is offered and in the subsequent semester

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
--
Module Group Theoretical Solid State Physics
(ECTS credits)
### Module title
Theoretical Solid State Physics

### Abbreviation
11-TFK-161-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

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### Contents
The contents of this two-term course will depend on the choice of the lecturer, and may include parts of the syllabus which could alternatively be offered as "Quantum Many Body Physics" (11-QVTP).

A possible syllabus may be:
1. Band structure (Sommerfeld theory of metals, Bloch theorem, k.p approach and effective Hamiltonians for topological insulators (TIs), bulk-surface correspondence, general properties of TIs)
2. Electron-electron interactions in solids (path integral method for weakly interacting fermions, mean field theory, random phase approximation (RPA), density functional theory)
3. Application of mean field theory and the RPA to magnetism
4. BCS theory of superconductivity

### Intended learning outcomes
During the two-semester lecture, the students acquire a basic understanding of many topics of Solid-State Physics, which are addressed in classical textbooks, and thereby advance their knowledge of the underlying concepts and the methods of description. The course builds upon the courses "Experimental Condensed Matter Physics" and "Quantum Mechanics".

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + R (2)

Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

--
**Module title**

Theoretical Solid State Physics 2

| Abbreviation | 11-TFK2-161-m01 |

**Module coordinator**

Managing Director of the Institute of Theoretical Physics and Astrophysics

**Module offered by**

Faculty of Physics and Astronomy

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**Contents**

A continuation of the first semester (11-TFK) might be the following syllabus:

5. Advanced topics of the theory of superconductivity (Bogoliubov-de Gennes equations, effective field theory, Anderson-Higgs description of the Meissner effect)

6. Unconventional superconductors (e.g. copper-oxide high-Tc superconductors)

7. Green's function methods and Feynman diagrammatic technique

8. The Kondo Effect (Anderson's "poor mans scaling", renormalization group)

**Intended learning outcomes**

During the two-semester lecture, the students acquire a basic understanding of many topics of Solid-State Physics, which are addressed in classical textbooks, and thereby advance their knowledge of the underlying concepts and the methods of description. The course builds upon the courses "Experimental Condensed Matter Physics" and "Quantum Mechanics".

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + R (2)

Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

--
### Module title
Phenomenology and Theory of Superconductivity

### Abbreviation
11-PTS-201-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
6

### Method of grading
Numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
Graduate

### Other prerequisites
--

## Contents


## Intended learning outcomes

Acquisition of basic knowledge about superconductivity as a macroscopic quantum phenomenon. Profound understanding of unconventional superconductivity and its interplay with magnetism in the context of current research. Knowledge of BCS mean-field theory, the quantum-field theory methods necessary to extend BCS theory, as well as the Meissner effect and the Higgs mechanism. Basic understanding of unconventional superconductors and their fascinating connection with competing magnetic phases.

## Courses

V (3) + R (1)

Module taught in: German or English

## Method of assessment

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Language of assessment: German and/or English

Assessment offered: In the semester in which the course is offered and in the subsequent semester

### Allocation of places

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### Additional information

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## Module Catalogue for the Subject
Mathematical Physics
Master's with 1 major, 120 ECTS credits

<table>
<thead>
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<tr>
<td>Topological Effects in Solid State Physics</td>
<td>11-TEFK-201-m01</td>
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### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

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Faculty of Physics and Astronomy

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### Contents
1. Geometric phase in quantum systems
2. Mathematical basics of topology
3. Time-reversal symmetry
4. Hall conductance and Chern numbers
5. Bulk-boundary correspondence
6. Graphene (as a topological insulator)
7. Quantum Spin Hall insulators
8. $\mathbb{Z}_2$ invariants
9. Topological superconductors

### Intended learning outcomes
In-depth theoretical understanding of the topological concepts in quantum physics related to solid state systems. Ability to connect their knowledge with different research activities at the Department of Physics and Astronomy at Würzburg University.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + R (1)

Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German and/or English

Assessment offered: In the semester in which the course is offered and in the subsequent semester

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

--
### Field Theory in Solid State Physics

#### Module title
Field Theory in Solid State Physics

#### Abbreviation
11-FFK-201-m01

#### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

#### Module offered by
Faculty of Physics and Astronomy

#### ECTS
8

#### Method of grading
Numerical grade

#### Duration
1 semester

#### Module level
Graduate

#### Other prerequisites
--

### Contents
This will usually be a course on quantum many particle physics approached by the perturbative methods using Green's functions.

An outline could be:
1. Single-particle Green's function
2. Review of second quantization
3. Diagrammatic method using many particle Green's functions at temperature $T=0$
4. Diagrammatic method for finite $T$
5. Landau theory of Fermi liquids
6. Superconductivity
7. One-dimensional systems and bosonization

### Intended learning outcomes
Working knowledge of the methods of quantum field theory in a non-relativistic context. Ability to study properties of Fermi liquids (and bosonic systems) beyond the one-particle picture. Acquisition of methods which are essential for the understanding the effects of interactions, including superconductivity and the Kondo effect.

### Courses
(V (4) + R (2))
Module taught in: German or English

### Method of assessment
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Language of assessment: German and/or English

Assessment offered: In the semester in which the course is offered and in the subsequent semester

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<td>Selected Topics of Theoretical Solid State Physics</td>
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**Contents**

In this lecture, selected topics of condensed matter theory are addressed. We intend to present new developments to bring the students in touch with actual research topics. Possible subjects are many-body localization and dynamic quantum matter.

**Intended learning outcomes**

The students learn how to describe condensed matter systems in presence of disorder and interactions from a theoretical point of view. This happens on the basis of analytical and numerical methods. Therefore, we envisage a smooth crossover of these students to the next step of becoming a researcher.

**Courses**

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Module taught in: German or English

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Language of assessment: German and/or English

Assessment offered: In the semester in which the course is offered and in the subsequent semester

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title
Computational Materials Science (DFT)

### Abbreviation
11-CMS-161-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
8

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
1. Density functional theory (DFT)
2. Wannier functions and localized basis functions
3. Numerical evaluation of topological invariants
4. Hartree-Fock and static mean-field theory
5. Many-body methods for solid state physics
6. Anderson impurity model (AIM) and Kondo physics
7. Dynamical mean-field theory (DMFT)
8. DFT + DMFT methods for realistic modeling of solids
9. Strongly correlated electrons

### Intended learning outcomes
Aside from the theoretical discussion of these topics, the students carry out hands-on exercises from the CIP pool. The participants are introduced to the use of DFT software packages such as VASP or Wien2k and to the construction of maximally localised Wannier functions through the projection of DFT results on atom orbitals with the software wannier90. Furthermore, the students learn how to construct many-particle solutions of AIM and observe border cases such as the Kondo regime. Impurity solvers such as exact diagonalisation or continuous-time quantum Monte Carlo are utilised to solve the self consistency equations of dynamic molecular field theory (DMFT). These steps are necessary to reach the peak of the lecture: a DFT-DMFT calculation of a strongly correlated transition metal oxide such as SrVO3.

### Courses
V (4) + R (2)
Module taught in: German or English

### Method of assessment
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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Module title
Conformal Field Theory
Abbreviation
11-KFT-161-m01

Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

Module offered by
Faculty of Physics and Astronomy

ECTS
6

Method of grading
numerical grade

Only after succ. compl. of module(s)
--

Duration
1 semester

Module level
graduate

Other prerequisites
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Contents
Conformal field theory (CFT) was developed in the 1980s and found immediate application in string theory and two-dimensional statistical mechanics, where critical exponents and correlation functions for many models (Ising, tricritical Ising, 3-state Potts, etc.) could be exactly calculated. The physical idea is that the principle of scale invariance is elevated from a global to a local invariance, which, for reasons of consistency, amounts to invariance under conformal transformations. This, in turn, yields a rich and fascinating mathematical structure for two dimensional systems (either two space dimensions or one time and one space dimension). CFT has become relevant to many interesting areas of condensed matter physics, including Abelian and non-Abelian bosonisation, quantised Hall states (where the bulk wave function is described in terms of conformal correlators, and the edge in terms of 1+1 dimensional CFTs), the two-channel Kondo effect, fractional topological insulators, and in particular fault-tolerant topological quantum computers involving non-Abelian anyons (Ising and Fibonacci anyons, for example, owe their names to the fusion rules of the associated conformal fields.) A potential syllabus for the first term of the course is:

0. Introduction (scale and conformal invariance, critical exponents, the transverse Ising model at the self-dual point)
1. Conformal theories in D dimensions (conformal group, conformal algebra in 2D, constraints on correlation functions)
2. Conformal theories in D=2 (primary fields and correlation functions, quantum field theory, canonical quantisation and Noether's theorem, radial quantisation and Polyakov's theorem, time ordering and functional integrals, the free boson and vertex operators, conformal Ward identities)
3. Central charge and Virasoro algebra (central charge, the Schwarzian derivative, free fermion, (Abelian) bosonisation, mode expansions and Virasoro algebra, cylinder geometry and Casimir effect, in- and out-states, highest weight states, descendant fields and operator product expansions, conformal blocks, duality and bootstrap)

Intended learning outcomes
The students acquire practical and conceptional familiarity with the methods of conformal field theory. As the completion of "Quantum Mechanics II" (11-QM2) is the only prerequisite to take part in this course, the students also acquire basic knowledge of critical phenomena, quantum field theory and functional integrals. The course is primarily addressed to students of Theoretical Physics and aims to increase their general level of knowledge by becoming acquainted with a sophisticated subdiscipline with applications in many subdisciplines of Condensed Matter Physics.

Courses
V (3) + R (1)
Module taught in: German or English

Method of assessment
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places

Additional information

Referred to in LPO I (examination regulations for teaching-degree programmes)
Module title | Abbreviation
---|---
Conformal Field Theory 2 | 11-KFT2-161-m01

Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

Module offered by
Faculty of Physics and Astronomy

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
6 | numerical grade | --

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | --

Contents
5. Minimal models (critical statistical mechanics models (Ising, tricritical Ising, 3 state Potts model, restricted solid-on-solid models), correlation functions of the critical Ising model, fusion rules and Verlinde algebra, Landau-Ginzburg description of minimal models, modified Coulomb gas method and its application to the Ising model, superconformal models)
6. Free bosons and fermions (mode expansions, twist fields, fermionic zero modes and fermion parity)
7. Free fermions on the torus (operator implementation of the partition function, vacuum energies, representations of Virasoro algebra, modular group and fermionic spin structures, Virasoro characters, critical Ising model on the torus, Jacobi theta function identities)
8. Free bosons on the torus (Lagrangian formulation of the partition function, fermionisation, orbifolds in general, $S_1/Z_2$ orbifold, Gaussian and Ashkin-Teller models, duality between original and orbifold theories, marginal operators, the space of $c=1$ theories)

Intended learning outcomes
The students acquire practical and conceptional familiarity with the methods of conformal field theory. As the completion of "Quantum Mechanics II" (11-QM2) is the only prerequisite to take part in this course, the students also acquire basic knowledge of critical phenomena, quantum field theory and functional integrals. The course is primarily addressed to students of Theoretical Physics and aims to increase their general level of knowledge by becoming acquainted with a sophisticated subdiscipline with applications in many subdisciplines of Condensed Matter Physics.

Courses (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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<td>Particle Physics (Standard Model)</td>
<td>11-TPSM-201-m01</td>
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<td>1 semester</td>
<td>graduate</td>
<td>Approval from examination committee required.</td>
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</table>

**Contents**

- Theoretical description of the Standard Model
- Electroweak symmetry breaking through the Higgs mechanism
- Parity Violation
- Bhabha scattering
- Z-Line Shape and forward / reverse asymmetry
- Higgs production and decay
- Experimental setup and results of key experiments to test the Standard Model and for determining its parameters
- Search for the Higgs boson

**Intended learning outcomes**

Students know the theoretical fundamental laws of the standard model of particle and the key experiments that have established and confirmed the standard model. They have basic knowledge in order to interpret experimental or theoretical results in the framework of the standard model and can knows its significance and limitations.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)
Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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- Language of assessment: German and/or English
- Assessment offered: In the semester in which the course is offered and in the subsequent semester

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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# Renormalization Group and Critical Phenomena

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<td>11-CRP-161-m01</td>
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## Contents
1. Phase transitions
2. Mean field theory
3. The concept of the renormalization group (RG) Phase diagrams and fixed points
4. Perturbation-theoretical renormalization group
5. Low-dimensional systems
6. Conformal symmetry

## Intended learning outcomes
The students acquire profound knowledge of the principles of scale invariance and of the renormalisation group (RG) in Statistical Physics. They understand the concept of RG flow with respect to effective field theories in both statistical and quantum field theory.

## Courses
V (3) + R (1)
Module taught in: German or English

## Method of assessment
Written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

## Allocation of places
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## Additional information
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## Referred to in LPO I
(examination regulations for teaching-degree programmes)
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Module title | Abbreviation
---|---
Bosonisation and Interactions in One Dimension | 11-BWW-161-m01

Module coordinator | Module offered by
Managing Director of the Institute of Theoretical Physics and Astrophysics | Faculty of Physics and Astronomy

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Duration | Module level | Other prerequisites
1 semester | graduate | --

Contents
1. Instability of Fermi systems in one dimension (1D)
2. Abelian bosonisation and Luttinger liquids (spinless fermions, correlation functions, models with spin, renormalization group, and the sine-Gordon model).

The below mentioned topics will be presented in different years:
3. Interacting fermions on a lattice (Hubbard model, t/J model, transport properties)
4. Bethe ansatz
5. Spin-1/2 chains
6. Disordered systems
7. Non-abelian bosonisation and the WZW model (Kac-Moody algebras, Sugawara construction, Knizhnik-Zamolodchikov equation, applications of the WZW model)

Intended learning outcomes
The students become familiar with the peculiarities of one-dimensional (1D) electron systems and acquire the theoretical tools to understand phenomena relevant to experiments, including disorder effects and transport in 1D.

Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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<td>Introduction to Gauge/Gravity Duality</td>
<td>11-GGD-161-m01</td>
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</table>

**Contents**

1. Elements of quantum field theory:
   - Quantisation of the free field
   - Interactions
   - Renormalisation Group
   - Gauge Fields
   - Conformal Symmetry
   - Large N expansion
   - Supersymmetry

2. Elements of gravity
   - Manifolds, coordinate covariance and metric
   - Riemann curvature
   - Maximally symmetric spacetimes
   - Black holes

3. Elements of string theory
   - Open and closed strings
   - Strings in background fields
   - Type IIB String Theory
   - D-Branes

4. The AdS/CFT correspondence
   - Statement of the correspondence
   - Near-horizon limit of D3-Branes
   - Field-operator correspondence
   - Tests of the correspondence: Correlation functions
   - Tests of the correspondence: Conformal anomaly
   - Holographic principle

5. Extensions to non-conformal theories
   - Holographic renormalisation group
   - Holographic C-Theorem

6. Applications I: Thermo- and hydrodynamics
   - Quantum field theory at finite temperature
   - Black holes
   - Holographic linear response formalism
   - Transport coefficients: Shear viscosity and conductivities

7. Applications II: Condensed matter physics
   - Finite charge density and Reissner-Nordström black holes
   - Quantum critical behaviour
   - Holographic fermions
- Holographic superconductors
- Entanglement entropy

8. Applications III: Particle physics
- Gravity dual of confinement
- Gravity dual of chiral symmetry breaking
- Quark-gluon plasma

**Intended learning outcomes**

The students acquire a thorough understanding of the foundations of gauge/gravity duality and the ability to carry out basic tests. Depending on the pre-existing knowledge and interests of the students, the module addresses a selection of the aforementioned topics. Knowledge of quantum mechanics and classical electrodynamics is a prerequisite for this course. Knowledge of quantum field theory and general relativity is useful, but not a prerequisite.

**Courses**

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<th>Type</th>
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<td>V (4) + R (2)</td>
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Module taught in: German or English

**Method of assessment**

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(Examination regulations for teaching degree programmes)
Module Group Astrophysics

(ECTS credits)
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<th>Module title</th>
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<td>Cosmology</td>
<td>11-AKM-161-m01</td>
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<td>1 semester</td>
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**Contents**

Expanding space-time, Friedmannian cosmology, basics of general relativity, the early universe, inflation, dark matter, primordial nucleosynthesis, cosmic microwave background, structure formation, galaxies and galaxy clusters, intergalactic medium, cosmological parameters.

**Intended learning outcomes**

The students have basic knowledge of cosmology. They know the theoretical methods of cosmology and are able to relate them to observations. They have gained insights into current research topics and are able to process scientific questions.

**Courses**

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<td>V (3) + R (1)</td>
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Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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<table>
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<td>Theoretical Astrophysics</td>
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**Contents**

Topics in theoretical astrophysics such as e.g. white dwarfs, neutron stars and black holes, supernovae, pulsars, accretion and jets, shock waves, radiation transport, and gravitational lensing

**Intended learning outcomes**

Knowledge of basic processes and methods of Theoretical Astrophysics. Ability to formulate theoretical models.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + R (2)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>Introduction to Plasma Physics</td>
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**Contents**

Plasma Astrophysics: Dynamics of charged particles in electric and magnetic fields, magnetohydrodynamics, transport equations for energetic particles, properties of magnetic turbulence, propagation of solar particles within the solar wind, particle acceleration via shock waves and via interaction with plasma turbulence, particle acceleration and transport in galaxies and other astrophysical objects, cosmic radiation.

**Intended learning outcomes**

The students have knowledge of the basic processes of Plasma Astrophysics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + R (2)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>High Energy Astrophysics</td>
<td>11-APL-161-m01</td>
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<th>Module coordinator</th>
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</table>

**Contents**
Radiative processes, interaction of light with matter, particle acceleration processes, pair creation, nuclear processes, pion production, astrophysical shock waves, kinetic equations

**Intended learning outcomes**
The student gains knowledge in fundamentals of High-Energy Astrophysics, such as particle acceleration and non-thermal radiative processes in astrophysical objects

**Courses** (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
--
Module title | Abbreviation
--- | ---
Computational Astrophysics | 11-NMA-161-m01

Module coordinator | Module offered by
Managing Director of the Institute of Theoretical Physics and Astrophysics | Faculty of Physics and Astronomy

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</table>

Contents


Intended learning outcomes

The students are able to solve typical problems and equations of Astrophysics and other subdisciplines of Physics with the help of numerical simulations. They are especially capable of choosing adequate strategies to approach such problems and of validating the results.

Courses (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes) or b) oral examination of one candidate each (approx. 30 minutes) or c) oral examination in groups (groups of 2, approx. 30 minutes per candidate) or d) project report (approx. 8 to 10 pages) or e) presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

--
Module Group Theoretical Elementary Particle Physics

(ECTS credits)
### Module title
Quantum Field Theory I

### Abbreviation
11-QFT1-201-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
8

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
graduate

### Other prerequisites
Approval from examination committee required.

### Contents
1. Symmetries.
2. Lagrange formalism for fields.
3. Field quantisation.
4. Asymptotic states, scattering theory and S-matrix
5. Gauge principle and interaction.
6. Perturbation theory.
7. Feynman rules.
8. Quantum electrodynamical processes in Born approximation.
9. Radiative corrections (optional)
10. Renormalisation (optional).

### Intended learning outcomes
The students have mastered the principles and underlying mathematics of relativistic quantum field theories. They know how to use perturbation theory and how to apply Feynman rules. They are able to calculate basics processes in the framework of quantum electrodynamics in leading order. Moreover, they have a basic understanding of radiative corrections and renormalisation.

### Courses (type, number of weekly contact hours, language — if other than German)
V (4) + R (2)

Module taught in: German or English

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Language of assessment: German and/or English

Assessment offered: In the semester in which the course is offered and in the subsequent semester

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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## Module Catalogue for the Subject
### Mathematical Physics
#### Master's with 1 major, 120 ECTS credits

<table>
<thead>
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<tbody>
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<td>Quantum Field Theory II</td>
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### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

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### Contents
1. Generating Functionals
2. Path Integrals
3. Renormalization
4. Renormalization group
5. Gauge theories
6. Spontaneous Symmetry Breaking
7. Effective Field Theory (optional)

### Intended learning outcomes
The students have advanced knowledge of the methods and concepts of quantum field theory. They have mastered the principles, especially of renormalisation and gauge theories. They are able to formulate and solve problems of quantum field theory by using the acquired calculation methods.

### Courses
(type, number of weekly contact hours, language — if other than German)

- V (4) + R (2)
- Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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- Assessment offered: In the semester in which the course is offered and in the subsequent semester
- Language of assessment: German and/or English

### Allocation of places
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### Additional information
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**Contents**

1. Fundamental particles and forces
2. Symmetries and groups
3. Quark model of hadrons
4. Quark parton model and deep inelastic scattering
5. Principles of quantum field theory
6. Gauge theories
7. Spontaneous symmetry breaking
8. Electroweak standard model
9. Quantum chromo dynamics
10. Extensions of the standard model.

**Intended learning outcomes**

The students are familiar with the mathematical methods of Elementary Particle Physics. They understand the structure of the standard model based on symmetry principles and experimental observations. They know calculation methods for the processing of simple problems and processes of Elementary Particle Physics. Furthermore, they know the tests and limits of the standard model and the basics of extended theories.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + R (2)

Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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<td>Selected Topics of Theoretical Elementary Particle Physics</td>
<td>11-ATTP-161-m01</td>
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**Contents**

A selection of topics from the following fields will be covered in different years:
1. Advanced techniques for precision calculations of scattering amplitudes
2. Phenomenology of particle accelerators
3. Higgs physics
4. Top quark physics

**Intended learning outcomes**

The students are familiar with the tests and limits of the standard model of Particle Physics, Higgs physics and neutrino physics. They are able to formulate extensions of the standard model. Furthermore, they know how to test these extensions in low energy experiments, at high energy colliders and in cosmology.

**Courses** (type, number of weekly contact hours, language — if other than German)

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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
Module title: String Theory 1

Abbreviation: 11-STRG1-171-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics

Module offered by: Faculty of Physics and Astronomy

ECTS: 8

Method of grading: numerical grade

Only after succ. compl. of module(s): --

Duration: 1 semester

Module level: graduate

Other prerequisites: --

Contents:
Classical and quantum theory of the relativistic bosonic string, in particular the Nambu-Goto action and Polyakov action; quantisation of the closed bosonic string and emergent graviton; quantum Lorentz invariance and critical dimension; quantisation of the open bosonic string, D-Branes, Gauge Fields and Yang-Mills theories; relativistic conformal field theory, string path integral, BRST quantisation, string interactions, effective actions and gravity.

Intended learning outcomes:
The students are familiar with classical and quantum theory of relativistic bosonic strings. They know the classical actions for relativistic bosonic strings, the Nambu-Goto action and Polyakov action, they have quantised the bosonic string and understand the emergence of the massless graviton in the spectrum of the closed string. They have calculated Lorentz anomaly on quantum level to deduce the critical dimension of the bosonic string. They understand the boundary conditions for the open string and its connection to D-branes. They have knowledge of open string quantisation and of the spectrum of massless gauge fields, as well as of Yang-Mills fields for coincident branes. They are familiar with relativistic conformal field theory, the string path integral, its BRST quantisation and the calculation of string interactions. They understand the low-energy effective actions in target space and the emergence of Einstein gravity.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + R (2)

Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus):

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

Allocation of places:
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Additional information:
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Module title: String Theory 2
Abbreviation: 11-STRG2-171-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics
Module offered by: Faculty of Physics and Astronomy

ECWS  Method of grading  Only after succ. compl. of module(s)
6   numerical grade  --

Duration  Module level  Other prerequisites
1 semester  graduate  --

Contents
Superstring theories and M theory, in particular a short introduction to bosonic string theory, the theory of fermionic fields and representations of Clifford algebra in diverse dimensions, a review of supersymmetry in two and more dimensions, the classical and quantum version of the Ramond-Neveu-Schwarz superstring, type II A/B superstrings, the Gliozzi-Scherck-Olive projection and space-time supersymmetry in 10 dimensions, the type I superstring, heterotic string theories, anomaly cancellation and restrictions on gauge groups, dualities between the five superstring theories as well as their relation to M theory in 11D, D-Branes and supersymmetric gauge theories, supergravity and the AdS/CFT correspondence.

Intended learning outcomes
The students are familiar with supersymmetrical string theory and M theory. They know the basic characteristics of bosonic string theory and fermionic field theory as well as the depiction of Clifford algebra in different dimensions. They have studied the aspects of supersymmetry in two or more dimensions relevant to superstring theory. They are acquainted with classical and quantum theory of the Ramon-Neveu-Schwarz superstring, they understand the deduction of type IIA/B string theories and the ensuring of space-time supersymmetry on the basis of Gliozzi-Scherk-Olive projection. They have gained insights into type I and heterotic superstring theory and into the limiting effects of anomaly freedom on the permitted gauge groups of these theories. They have studied the dualities between the five superstring theories and their connections to M theory in 11 dimensions. They are familiar with the properties of supersymmetric D-branes in type I and II superstring theories and the corresponding supersymmetric gauge theories as well as the supergravity effects in 10 and 11 dimensions and the connection to AdS/CFT correspondence.

Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Module title | Abbreviation
---|---
Models Beyond the Standard Model of Elementary Particle Physics | 11-BSM-161-m01

Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

Module offered by
Faculty of Physics and Astronomy

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Duration
1 semester

Module level
graduate

Other prerequisites
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Contents
1. Principles of the standard model of Elementary Particle Physics
2. Tests of the standard model in low energy experiments and at high energy colliders
3. Neutrino physics
4. Higgs physics.

In addition, a selection of topics from the following fields will be covered in different years:
- Phenomenology of experiments at the LHC,
- particle cosmology,
- extended gauge theories,
- models with extended Higgs sectors,
- supersymmetry,
- models with additional space-time dimensions

Intended learning outcomes
The students are familiar with the tests and limits of the standard model of Particle Physics, Higgs physics and neutrino physics. They are able to formulate extensions of the standard model. Furthermore, they know how to test these extensions in low energy experiments, at high energy colliders and in cosmology.

Courses (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Module Group Current Topics
(ECTS credits)
Module title: Current Topics of Mathematical Physics

Abbreviation: 11-EXMP5-161-m01

Module coordinator: chairperson of examination committee

Module offered by: Faculty of Physics and Astronomy

ECTS: 5

Method of grading: numerical grade

Only after succ. compl. of module(s)

Duration: 1 semester

Module level: graduate

Other prerequisites: Approval from examination committee required.

Contents:
Current topics in Mathematical Physics. Credited academic achievements, e.g. in case of change of university or study abroad.

Intended learning outcomes:
The students have advanced competencies corresponding to the requirements of a module of Mathematical Physics of the Master's programme. They have knowledge of a current subdiscipline of Mathematical Physics and understand the methods necessary to acquire this knowledge. They are able to classify the subject-specific contexts and know the application areas.

Courses:

(type, number of weekly contact hours, language — if other than German)
V (2) + R (2)

Method of assessment:
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Language of assessment: German and/or English

Allocation of places:

Additional information:

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<td>If a written examination was chosen as method of assessment, this may be changed and assessment may instead take the form of an oral examination of one candidate each or an oral examination in groups. If the method of assessment is changed, the lecturer must inform students about this by four weeks prior to the original examination date at the latest.</td>
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</table>
Module title: Current Topics of Mathematical Physics  
Abbreviation: 11-EXMP7-161-m01

Module coordinator: Chairperson of examination committee  
Module offered by: Faculty of Physics and Astronomy

ECTS: 7  
Method of grading: Numerical grade  
Only after success completion of module(s)

Duration: 1 semester  
Module level: Graduate  
Other prerequisites: Approval from examination committee required.

Contents:
Current topics in Mathematical Physics. Credited academic achievements, e.g. in case of change of university or study abroad.

Intended learning outcomes:
The students have advanced competencies corresponding to the requirements of a module of Mathematical Physics of the Master's programme. They have knowledge of a current subdiscipline of Mathematical Physics and understand the methods necessary to acquire this knowledge. They are able to classify the subject-specific contexts and know the application areas.

Courses:
V (3) + R (1)

Method of assessment:
(a) written examination (approx. 90 to 120 minutes) or (b) oral examination of one candidate each (approx. 30 minutes) or (c) oral examination in groups (groups of 2, approx. 30 minutes per candidate) or (d) project report (approx. 8 to 10 pages) or (e) presentation/talk (approx. 30 minutes).

If a written examination was chosen as method of assessment, this may be changed and assessment may instead take the form of an oral examination of one candidate each or an oral examination in groups. If the method of assessment is changed, the lecturer must inform students about this by four weeks prior to the original examination date at the latest.

Language of assessment: German and/or English

Allocation of places:

Additional information:

Referred to in LPO I (examination regulations for teaching-degree programmes):
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<td>11-EXMP8-161-m01</td>
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<tr>
<td>chairperson of examination committee</td>
<td>Faculty of Physics and Astronomy</td>
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<tr>
<td>1 semester</td>
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### Contents

Current topics of Mathematical Physics. Accredited academic achievements, e.g. in case of change of university or study abroad.

### Intended learning outcomes

The students have advanced competencies corresponding to the requirements of a module of Mathematical Physics of the Master’s programme. They have knowledge of a current subdiscipline of Mathematical Physics and understand the methods necessary to acquire this knowledge. They are able to classify the subject-specific contexts and know the application areas.

### Courses

(type, number of weekly contact hours, language — if other than German)

- V (4) + R (2)

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes) or b) oral examination of one candidate each (approx. 30 minutes) or c) oral examination in groups (groups of 2, approx. 30 minutes per candidate) or d) project report (approx. 8 to 10 pages) or e) presentation/talk (approx. 30 minutes).

If a written examination was chosen as method of assessment, this may be changed and assessment may instead take the form of an oral examination of one candidate each or an oral examination in groups. If the method of assessment is changed, the lecturer must inform students about this by four weeks prior to the original examination date at the latest.

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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Subfield Research in Groups
(min. 10 ECTS credits)
### Module title
Research in Groups - Algebra

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Research in Groups - Algebra</td>
<td>10-M=GALG-161-m01</td>
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

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### Duration
1 semester

### Module level
graduate

### Other prerequisites
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### Contents
Selected modern topics in algebra (e.g. ring theory, commutative algebra, differential algebra, local fields, computer algebra, algebras, division rings, quadratic forms).

### Intended learning outcomes
The student gains insight into contemporary research problems in algebra. He/She masters advanced techniques in this field and can apply them to complex problems.

### Courses
(type, number of weekly contact hours, language — if other than German)

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<thead>
<tr>
<th>Type</th>
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Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

### Language of assessment
German or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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<table>
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<th>Module title</th>
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<td>Research in Groups - Discrete Mathematics</td>
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<tr>
<td>1 semester</td>
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</table>

**Contents**

Selected modern topics in discrete mathematics.

**Intended learning outcomes**

The student gains insight into contemporary research problems in discrete mathematics. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

<table>
<thead>
<tr>
<th>V (2) + S (2)</th>
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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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**Allocation of places**

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<th>Module title</th>
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<tbody>
<tr>
<td>Research in Groups - Dynamical Systems and Control Theory</td>
<td>10-M=GDSC-161-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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</table>

**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
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**Contents**
Selected modern topics in dynamical systems and control theory.

**Intended learning outcomes**
The student gains insight into contemporary research problems in dynamical systems and control theory. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)

V (2) + S (2)
Module taught in: German and/or English

**Method of assessment**
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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<tr>
<td>Research in Groups - Complex Analysis</td>
<td>10-M=GCOA-161-m01</td>
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**Module coordinator**

Dean of Studies Mathematik (Mathematics)

**Module offered by**

Institute of Mathematics

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</table>

**Duration**

1 semester

**Module level**

graduate

**Other prerequisites**

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**Contents**

Selected modern topics in complex analysis (e.g. in approximation theory, potential theory, complex dynamics, geometric complex analysis, value distribution theory).

**Intended learning outcomes**

The student gains insight into contemporary research problems in complex analysis. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

**talk (60 to 120 minutes)**

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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## Module Catalogue for the Subject
Mathematical Physics
Master’s with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Research in Groups - Geometry and Topology</td>
<td>10-M=GGMT-161-m01</td>
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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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</table>

### Contents
Selected modern topics in geometry and topology.

### Intended learning outcomes
The student gains insight into contemporary research problems in geometry and topology. He/She masters advanced techniques in this field and can apply them to complex problems.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (2) + S (2)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

**Talk (60 to 120 minutes)**
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)
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### Module title

Research in Groups - Mathematics in Context

### Abbreviation

10-M=GMCX-161-m01

### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

### ECTS

| 10 | numerical grade |

### Method of grading

Only after succ. compl. of module(s)

### Duration

1 semester

### Module level

graduate

### Other prerequisites

--

### Contents

Reflection on mathematics in a cultural context, for example by discussing part of the history of mathematics, given by a historical period, a geographic region or a particular field of mathematics. Other possibilities arise from the connection of mathematics with literature, language, music, art or the media.

### Intended learning outcomes

The student realises the cultural dimension of mathematics and its relation to other cultural fields.

### Courses

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Module taught in: German and/or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

### Allocation of places

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### Additional information

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<td>Research in Groups - Mathematics in the Sciences</td>
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<td>1 semester</td>
<td>graduate</td>
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</table>

**Contents**

A modern topic in mathematics in the sciences.

**Intended learning outcomes**

The student gains insight into contemporary research problems in mathematics in the sciences. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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<td>Research in Groups - Measure and Integral</td>
<td>10-M=GMAI-161-m01</td>
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</table>

Contents

Aspects of measure and integration theory: sigma algebras and Borel sets, volume and measure, measurable functions and Lebesgue integrals, selected applications, e. g. product measures (with Fubini’s theorem and the transformation rule), Lp spaces and absolute continuity, measures on topological spaces.

Intended learning outcomes

The student gains insight into contemporary research problems in measure and integration theory. He/She masters advanced techniques in this field and can apply them to complex problems.

Courses

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<th>Type</th>
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Module taught in: German and/or English

Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Allocation of places

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Additional information

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<td>Research in Groups - Numerical Mathematics and Applied Analysis</td>
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</table>

**Contents**

Selected topics in numerical mathematics, applied analysis or scientific computing.

**Intended learning outcomes**

The student gains insight into a contemporary research problems in numerical mathematics or applied analysis. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
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<tbody>
<tr>
<td>Research in Groups - Robotics, Optimization and Control Theory</td>
<td>10-M=GROC-161-m01</td>
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**Module coordinator**  
Dean of Studies Mathematik (Mathematics)

**Module offered by**  
Institute of Mathematics

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**Duration**  
1 semester  

**Module level**  
Graduate  

**Other prerequisites**  
--

**Contents**

Selected modern topics in robotics, optimisation and control theory.

**Intended learning outcomes**

The student gains insight into contemporary research problems in robotics, optimization and control theory. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**  
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**Additional information**  
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>Research in Groups - Time Series Analysis</td>
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**Contents**

Selected modern topics in time series analysis.

**Intended learning outcomes**

The student gains insight into contemporary research problems in time series analysis. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**

(type, number of weekly contact hours, language — if other than German)

- V (2) + S (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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**Contents**
Selected modern topics in statistics.

**Intended learning outcomes**
The student gains insight into contemporary research problems in statistics. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)
V (2) + S (2)
Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I**  
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<td>Research in Groups - Number Theory</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
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**Contents**
Selected modern topics in number theory (e.g. algebraic number theory, modular forms, diophantine analysis).

**Intended learning outcomes**
The student gains insight into contemporary research problems in number theory. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)
V (2) + S (2)
Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Contents**

Selected modern topics in control theory of quantum mechanical systems.

**Intended learning outcomes**

The student gains insight into contemporary research problems in control theory of quantum mechanical systems. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Selected modern topics in differential geometry.

**Intended learning outcomes**

The student gains insight into contemporary research problems in Differential Geometry. He/She masters advanced techniques in this field and can apply them to complex problems.

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<th>Courses</th>
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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- Talk (60 to 120 minutes)
  - Assessment offered: In the semester in which the course is offered and in the subsequent semester
  - Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
## Module Title

**Research in Groups - Deformation Quantization**

### Abbreviation

10-M=GDFQ-161-m01

### Module Coordinator

Dean of Studies Mathematik (Mathematics)

### Module Offered by

Institute of Mathematics

### ECTS

10

### Method of Grading

Numerical grade

### Only after Succ. Compl. of Module(s)

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### Duration

1 semester

### Module Level

Graduate

### Other Prerequisites

--

### Contents

Selected modern topics in deformation quantization.

### Intended Learning Outcomes

The student gains insight into contemporary research problems in Deformation Quantization. He/She masters advanced techniques in this field and can apply them to complex problems.

### Courses

**Type**, number of weekly contact hours, language — if other than German:

- **V (2) + S (2)**

Module taught in: German and/or English

### Method of Assessment

**Type**, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus:

- **Talk (60 to 120 minutes)**

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

### Allocation of Places

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### Additional Information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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Module title | Abbreviation
---|---
Research in Groups - Non-linear Analysis | 10-M=GNLA-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
10 | numerical grade | ---

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | ---

Contents
Selected modern topics in non-linear analysis.

Intended learning outcomes
The student gains insight into contemporary research problems in Non-linear Analysis. He/She masters advanced techniques in this field and can apply them to complex problems.

Courses (type, number of weekly contact hours, language — if other than German)
V (2) + S (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

Allocation of places
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Additional information
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**Module offered by**
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**Contents**
Selected modern topics in operator algebras.

**Intended learning outcomes**
The student gains insight into contemporary research problems in Operator algebras. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)

- V (2) + S (2)
Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Contents**

Selected modern topics in Lie Theory.

**Intended learning outcomes**

The student gains insight into contemporary research problems in Lie Theory. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (approx. 60 to 120 minutes)

Language of assessment: German or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject Mathematical Physics

#### Master’s with 1 major, 120 ECTS credits

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#### Module coordinator

- **Dean of Studies Mathematik (Mathematics)**
- **Institute of Mathematics**

#### ECTS

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#### Duration

- **1 semester**
- **graduate**
- **--**

#### Contents

- Selected modern topics in Applied Differential Geometry.

#### Intended learning outcomes

The student gains insight into contemporary research problems in Applied Differential Geometry. He/She masters advanced techniques in this field and can apply them to complex problems.

#### Courses

- **V (2) + S (2)**
- Module taught in: German and/or English

#### Method of assessment

- **talk (approx. 60 to 120 minutes)**
- Language of assessment: German or English
- Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester

#### Allocation of places

- **--**

#### Additional information

- **--**

#### Referred to in LPO I

(examination regulations for teaching-degree programmes)

- **--**
## Module title

Research in Groups - Mathematical Physics

## Abbreviation

10-M=GMAP-192-m01

## Module coordinator

Dean of Studies Mathematik (Mathematics)

## Module offered by

Institute of Mathematics

## ECTS

10

## Method of grading

numerical grade

## Only after succ. compl. of module(s)

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## Duration

1 semester

## Module level

graduate

## Other prerequisites

--

## Contents

Selected modern topics in Mathematical Physics.

## Intended learning outcomes

The student gains insight into contemporary research problems in Mathematical Physics. He/She masters advanced techniques in this field and can apply them to complex problems.

## Courses

(type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

## Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (approx. 60 to 120 minutes)

Language of assessment: German or English

Assessment offered: Only when announced in the semester in which the courses are offered and in the subsequent semester

## Allocation of places

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## Additional information

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## Referred to in LPO I (examination regulations for teaching-degree programmes)

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**Contents**

Introduction to current questions of modern differential geometry as a preparation for a Master’s thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of modern differential geometry and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Introduction to current questions of symplectic geometry and Poisson geometry as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of Symplectic and Poisson geometry and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title
Study Group Operator Algebras and Representation Theory

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### Contents
Introduction to current questions of operator algebra as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

### Intended learning outcomes
The students have advanced knowledge of operator algebra and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

### Courses (type, number of weekly contact hours, language — if other than German)
S (4)
Module taught in: German or English

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

### Allocation of places
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### Additional information
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**Contents**

Introduction to current questions of Hopf algebra as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of Hopf algebra and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>Study Group Conformal Field Theorie</td>
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**Contents**

Introduction to current questions of conformal field theory as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of conformal field theory and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)
Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Introduction to current questions of statistical mechanics as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of statistical mechanics and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses**

(type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

**Talk (60 to 120 minutes)**

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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**Contents**

Introduction to current questions of quantum field theory as a preparation for a Master’s thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of quantum field theory and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

| talk (60 to 120 minutes) | Assessment offered: In the semester in which the course is offered and in the subsequent semester | Language of assessment: German and/or English |

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents

Introduction to current questions of Riemannian geometry as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

### Intended learning outcomes

The students have advanced knowledge of Riemannian geometry and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

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**Module title**

Study Group Riemannian Geometry

**Abbreviation**

11-AG-RGE-161-m01

**Module coordinator**

chairperson of examination committee

**Module offered by**

Faculty of Physics and Astronomy

**ECTS**

10

**Method of grading**

numerical grade

**Only after succ. compl. of module(s)**

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**Duration**

1 semester

**Module level**

graduate

**Other prerequisites**

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**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

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**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Introduction to current questions of Mathematical Physics as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of Mathematical Physics and have gained insights into current research topics. They are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Thesis

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**Contents**

Introduction to current questions of a subdiscipline of Mathematical Physics as a preparation for a Master's thesis in this area. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of a current subdiscipline of Mathematical Physics with a special relevance to the intended topic of the Master's thesis. They know the current state of research in this area and are able to summarise their knowledge in an oral presentation.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Introduction to the methods of scientific work, taking into account methods of project planning. Application to questions of Mathematical Physics. Writing of a scientific project plan for the planned Master's thesis.

**Intended learning outcomes**

The students have knowledge of scientific methods and methodological work, including project planning methods of a current subdiscipline of Mathematical Physics with special relevance to the intended topic of the Master's thesis. They are able to draft a project plan for the Master's thesis and to plan the required work. They are able to describe their projects in oral presentations.

**Courses**

(type, number of weekly contact hours, language — if other than German)

R (6)
Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)
Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**
(examination regulations for teaching-degree programmes)

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<td>The students are able to independently work on a task from Mathematical Physics, especially according to known methods and scientific aspects and to summarise their results in a final paper.</td>
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