Subdivided Module Catalogue
for the Subject

Physics

as a Master’s with 1 major
with the degree "Master of Science"
(120 ECTS credits)

Examination regulations version: 2016
Responsible: Faculty of Physics and Astronomy
Course of Studies - Contents and Objectives

The Master of Science programme prepares the students for their later scientific work in the field of experimental or theoretical physics. Qualified graduates may pursue doctoral work (degree Dr. rer. nat.) at doctorate-granting institutions. The objective of the education is to impart deepened knowledge of physical principles and of scientific working in research and applied physics. By training physical and analytical thinking skills the students are enabled to use their knowledge self-consistently and to transfer it to new challenges. Completing their Master thesis the graduates demonstrate their ability to solve an experimental or theoretical assignment within limited time using known scientific methods.
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)):

13-Apr-2016 (2016-68) except for mandatory elective 11-SSC-172 added in Fast Track procedure at a later time

14-Mar-2018 (2018-17)

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.
The subject is divided into

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<td>Object oriented Programming</td>
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<td>1 semester</td>
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</table>

**Contents**

Polymorphism, generic programming, meta programming, web programming, templates, document management.

**Intended learning outcomes**

The students are proficient in the different paradigms of object-oriented programming and have experience in their practical use.

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

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

Written examination (approx. 60 to 120 minutes). If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/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)

§ 22 II Nr. 3b
### Module title

**Computer Architecture**

### Abbreviation

10-I-RAK-152-m01

### Module coordinator

holder of the Chair of Computer Science V

### Module offered by

Institute of Computer Science

### ECTS

5

### Method of grading

numerical grade

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

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### Duration

1 semester

### Module level

undergraduate

### Other prerequisites

--

### Contents

Instruction set architectures, command processing through pipelining, statical and dynamic instruction scheduling, caches, vector processors, multi-core processors.

### Intended learning outcomes

The students master the most important techniques to design fast computers as well as their interaction with compilers and operating systems.

### Courses

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

V (2) + Ü (2)

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/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)

§ 69 I Nr. 1c: Rechnerarchitektur

§ 22 II Nr. 3b
<table>
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<td>Operating Systems</td>
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</table>

**Contents**

Introduction to computer systems, development of operating systems, architecture principles, interrupt processing in operating systems, processes and threads, CPU scheduling, synchronisation and communication, memory management, device and file management, operating system virtualisation.

**Intended learning outcomes**

The students possess knowledge and practical skills in building and using essential parts of operating systems.

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

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO 1** (examination regulations for teaching-degree programmes)

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**Contents**
Relational algebra and complex SQL statements; database planning and normal forms; transaction management.

**Intended learning outcomes**
The students possess knowledge about database modelling and queries in SQL as well as transactions.

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

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)
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If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/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)
§ 49 I Nr. 1b
§ 69 I Nr. 1b
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<td>Operations Research for students of other subjects</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**

undergraduate

**Other prerequisites**

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**Contents**

Linear programming, duality theory, transport problems, integral linear programming, graph theoretic problems.

**Intended learning outcomes**

The student is acquainted with the fundamental methods in operations research, as required as a central tool for solving many practical problems especially in economics. He/She is able to apply these methods to practical problems, both theoretically and numerically.

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

V (4) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

a) written examination (approx. 90 to 180 minutes, usually chosen) or b) oral examination of one candidate each (15 to 30 minutes) or c) oral examination in groups (groups of 2, 10 to 15 minutes per candidate)

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

Language of assessment: German and/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 | Abbreviation
--- | ---
Advanced Analysis | 10-M-VAN-152-m01

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

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

Duration Module level Other prerequisites
1 semester undergraduate --

Contents
Continuation of analysis in several variables, integration theorems.

Intended learning outcomes
The student is acquainted with advanced topics in analysis. Taking the example of the Lesbegue integral, he or she is able to understand the construction of a complex mathematical concept.

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

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)
a) written examination (approx. 90 to 180 minutes, usually chosen) or b) oral examination of one candidate each (15 to 30 minutes) or c) oral examination in groups (groups of 2, 10 to 15 minutes per candidate)
Language of assessment: German and/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
Electrochemical Energy Storage and Conversion

### Abbreviation
08-FU-EEW-152-m01

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### Contents
Chemistry and application of: battery systems (aqueous and non-aqueous systems like lead, nickel cadmium and nickel metal hydride, sodium sulfur, sodium nickel chloride, lithium ion accumulators), electrochemical double layer capacitors, redox-flow battery, fuel cell systems (AFC, PEMFC, DMFC, PAFC, SOFC), Solar cells (Si, CIS, CIGS, GaAs, organic and dye solar cell), thermoelectric devices.

### Intended learning outcomes
The students possess comprehensive knowledge in the field of electrochemical energy storage and transformation and are able to apply this to scientific problems.

### Courses (type, number of weekly contact hours, language — if other than German)
V (2) + P (1) + E (1)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)
a) assessment and b) Vortestate/Nachtestate (pre and post-experiment examination talks approx. 15 minutes each, log approx. 5 to 10 pages each) and assessment of practical assignments (2 to 4 random examinations), weighted 7:3
Assessment offered: Once a year, summer 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>

**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 can be chosen to earn a 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 Catalogue for the Subject

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

### Module title
Differential Geometry

### Abbreviation
10-M=ADGM-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
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 can be chosen to earn a 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 Catalogue for the Subject

**Physics**

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

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<tr>
<td>Complex Analysis</td>
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</tbody>
</table>

### 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

**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 can be chosen to earn a 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 Physics
## Master's with 1 major, 120 ECTS credits

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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 can be chosen to earn a 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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</table>

**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**

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

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

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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</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** (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 can be chosen to earn a 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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<thead>
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<th>Module title</th>
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<tr>
<td>Groups and their Representations</td>
<td>10-M=VGDS-161-m01</td>
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<th>Module offered by</th>
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</table>

**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 can be chosen to earn a 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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<td>Geometrical Mechanics</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**

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**

(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 can be chosen to earn a 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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### Numeral title
**Numeric of Partial Differential Equations**

<table>
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<tr>
<th>Abbreviation</th>
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### 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
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
(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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<td>Discrete Mathematics</td>
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</table>

**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 can be chosen to earn a 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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<table>
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<td>Selected Topics in Mathematical Physics</td>
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</table>

**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** (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 can be chosen to earn a 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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<table>
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<td>Partial Differential Equations of Mathematical Physics</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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</table>

### 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
(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 can be chosen to earn a 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
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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>
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<th>Module title</th>
<th>Abbreviation</th>
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<td>Pseudo Riemannian and Riemannian Geometry</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**
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 can be chosen to earn a 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 Catalogue for the Subject Physics
#### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Ultrafast spectroscopy and quantum-control</td>
<td>08-PCM4-161-m01</td>
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<tr>
<td>lecturer of the seminar &quot;Nanoskalige Materialien&quot;</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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<tr>
<td>1 semester</td>
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<td>Prior completion of modules 08-PCM1a and 08-PCM1b recommended.</td>
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### Contents

German contents available but not translated yet.

Das Modul behandelt spezielle Themen der Ultrakurzzeitspektroskopie und Quantenkontrolle. Schwerpunkte sind ultrakurze Laserimpulse, zeitaufgelöste Laserspektroskopie sowie kohärente Kontrolle.

### Intended learning outcomes

German intended learning outcomes available but not translated yet.


### Courses

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

S (2) + Ü (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 can be chosen to earn a bonus)

a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) talk (approx. 30 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

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<thead>
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<td>Analysis and Design of Programs</td>
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<td>Institute of Computer Science</td>
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<td>1 semester</td>
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</table>

**Contents**

Program analysis, model creation in software engineering, program quality, test of programs, process models.

**Intended learning outcomes**

The students are able to analyse programs, to use testing frameworks and metrics as well as to judge program quality.

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

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/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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<td>Artificial Intelligence 2</td>
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</table>

**Contents**

Intelligent agents, uninformed and heuristic search, constraint problem solving, search with partial information, propositional and predicate logic and inference, knowledge representation.

**Intended learning outcomes**

The students possess theoretical and practical knowledge about artificial intelligence in the area of agents, search and logic and are able to assess possible applications.

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

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO 1** (examination regulations for teaching-degree programmes)

--
Module title | Image and Signal Processing in Physics
---|---
Abbreviation | 11-BSV-161-m01

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

ECTS | 6
Method of grading | numerical grade
Duration | 1 semester
Module level | graduate
Other prerequisites | --

Contents
Periodic and aperiodic signals; principles of discrete and exact Fourier transformation; principles of digital signal and image processing; discretisation of signals/sampling theorem (Shannon); homogeneous and linear filters, convolution product; tapering functions and interpolation of images; the Parseval theorem, correlation and energetic observation; statistical signals, image noise, moments, stationary signals; tomography: Hankel and Radon transformation.

Intended learning outcomes
The students have advanced knowledge of digital image and signal processing. They know the physical principles of image processing and are familiar with different methods of signal processing. They are able to explain different methods and to implement them, especially in the field of tomography.

Courses
V (2) + Ü (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).

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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<table>
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<td>Quantum Information Technology</td>
<td>11-QUI-161-m01</td>
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<td>Managing Director of the Institute of Applied Physics</td>
<td>Faculty of Physics and Astronomy</td>
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</table>

### Contents

Basic concepts of quantum mechanics, quantum bits and algorithms, quantal measurements, experimental approaches towards quantum computing (on the basis of photons, ions and nuclear spins), quantum operations and quantum noise, quantum information and communication.

### Intended learning outcomes

The students are familiar with the basic quantum mechanical terms of quantum information technology. They know experimental approaches for the realisation of quantum computers and for the transfer of quantum information.

### 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 can be chosen to earn a 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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(examination regulations for teaching-degree programmes)

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<table>
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<tr>
<td>Physics of Advanced Materials</td>
<td>11-PMM-161-m01</td>
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<td>Managing Director of the Institute of Applied Physics</td>
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</table>

**Contents**

General properties of various material groups such as liquids, liquid crystals and polymers; magnetic materials and superconductors; thin films, heterostructures and superlattices. Methods of characterising these material groups; two-dimensional layer materials.

**Intended learning outcomes**

The students know the properties and characterization methods of some modern materials.

**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 can be chosen to earn a 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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Module title | Abbreviation
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Spintronics | 11-SPI-161-m01

Module coordinator | Module offered by
Managing Director of the Institute of Applied Physics | 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
This lecture covers the basic principles of spin transport, with a particular emphasis on the phenomena of giant magnetoresistance and tunnel magnetoresistance. As a last point, we discuss new phenomena from the field of spin dynamics and current-induced spin phenomena.

Intended learning outcomes
The students know the basic principles of spin transport models and the applications of spin transport in information technology. They have gained an overview of current findings in this field (giant magnetoresistance, tunnel magnetoresistance).

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 can be chosen to earn a bonus)
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Language of assessment: German and/or English

Allocation of places
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Additional information
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</table>

**Contents**

Modern scattering methods; neutron scattering as a method to investigate the atomic and magnetic structure and excitations such as phonons and magnetic waves; resonant elastic X-ray scattering and absorption; investigation of magnetic, orbital and charge order; X-ray and neutron reflectometry; investigation of the structural, magnetic and electronic properties of thin films and superlattices; resonant inelastic X-ray scattering; investigation of excitations in solids and thin films; STEM ("scanning transmission electron microscopy"); further topics upon agreement.

**Intended learning outcomes**

The students know different modern scattering methods such as neutron scattering, resonant elastic X-ray scattering, modern scattering theory, X-ray and neutron reflectometry and resonant inelastic X-ray scattering. They are familiar with the theoretical principles and applications of these 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 can be chosen to earn a bonus)

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- 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 Catalogue for the Subject Physics

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

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<td>Solid State Spectroscopy</td>
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### Contents


### Intended learning outcomes

The students have specific and advanced knowledge in the field of solid-state spectroscopy. They know different types of spectroscopy and their fields of application. They understand the theoretical principles and the current developments in research.

### Courses

*Module taught in: German or English*

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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**
Dia- and paramagnetism, exchange interaction, ferromagnetism, antiferromagnetism, anisotropy, domain structure, nanomagnetism, superparamagnetism, experimental methods to measure magnetic properties, Kondo effect.

**Intended learning outcomes**
The students know basic terms, concepts and phenomena of magnetism and measuring methods for magnetic experiments; they are skilled in simple model building and in the formulation of mathematical-physical approaches and are able to apply them to tasks in the stated areas; they have competencies in independently working on problems of these areas; they are able to evaluate the accuracy of observations and analyses.

**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 can be chosen to earn a bonus)
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<td>Semiconductor Physics</td>
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**Contents**

1. Symmetry properties  
2. Crystal formation and electronic band structure  
3. Optical excitations and their coupling effects  
4. Electron-phonon coupling  
5. Temperature-dependent transport properties  
6. Magnetic semiconductors

**Intended learning outcomes**

The students are familiar with the principles of Semiconductor Physics. They understand the structure of semiconductors and know their physical properties and effects. They know important applications.

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

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

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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**  
Optical Properties of Semiconductor Nanostructures

**Abbreviation**  
11-HNS-161-m01

**Module coordinator**  
Managing Director of the Institute of Applied Physics

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

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**Contents**

Semiconductor nanostructures are frequently referred to as "artificial materials". In contrast to atoms, molecules or macroscopic crystals, their electronic, optical and magnetic properties can be systematically tailored by changing their size. The lecture addresses technological challenges in the preparation of semiconductor nanostructures of varying dimensions (2D, 1D, 0D). It provides the basic theoretical concepts to describe their properties, with a focus on optical properties and light-matter coupling. Moreover, it discusses the challenges and concepts of novel optoelectronic and quantum photonic devices based on such nanostructures, including building blocks for quantum communication and quantum computing architectures.

**Intended learning outcomes**

The students know the theoretical principles and characteristics of semiconductor nanostructures. They have knowledge of the technological methods to fabricate such structures, and of their applications to novel photonic devices. They are able to apply their knowledge to problems in this field of research.

**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**

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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: Quantum Transport

Abbreviation: 11-QTH-161-m01

Module coordinator: Managing Director of the Institute of Applied Physics

Module offered by: Faculty of Physics and Astronomy

ECTS: 6

Method of grading: Only after succ. compl. of module(s)

Duration: 1 semester

Module level: graduate

Other prerequisites: --

Contents:
The lecture addresses the fundamental transport phenomena of electrons in nanostructures. This includes the topics of: ballistic and diffuse transport, electron interference effects, quantisation of conductivity, interaction phenomena between electrons, Coulomb blockade, thermoelectric properties, description of spin-dependent transport phenomena, topological insulators, solid-state quantum computers.

Intended learning outcomes:
The students have mastered the basics of electronics of nanostructures in theory and practice. They know functions and applications of respective components.

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

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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# Methods of Observational Astronomy

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<td>Methods of Observational Astronomy</td>
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## Contents

Methods of observational astronomy across the electromagnetic spectrum. Evaluation of observational data from radio, optical, X-ray and gamma-ray telescopes.

## Intended learning outcomes

Overview of the methods used in observational astronomy in various parts of the electromagnetic spectrum (radio, optical, X-ray and gamma-ray energies). Knowledge of principles and applications of these methods and ability to conduct astronomical observations.

## Courses

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<td>Experimental Particle Physics</td>
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**Contents**

Physics with modern particle detectors at the LHC and at the Tevatron. Discovery of the Higgs boson. Search for supersymmetry and other physics beyond the standard model. Determination of the top quark mass and W mass as well as other parameters of the standard model. Introduction to modern methods of analysis and assessment of systematic errors.

**Intended learning outcomes**

The students are familiar with the principles of modern particle detector physics, especially with currently open questions of Particle Physics, which are examined by using these detectors. They know modern methods of analysis and are able to put results into context and to assess their systematic uncertainties.

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

V (3) + R (1)

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<tr>
<td>1 semester</td>
<td>graduate</td>
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**Contents**

1. Overview  
2. Dynamics of charged particles in magnetic and electric fields  
3. Elements of space physics  
4. The sun and heliosphere  
5. Acceleration and transport of energetic particles in the heliosphere  
6. Instruments to measure energetic particles in extraterrestrial space

**Intended learning outcomes**

The students acquire basic knowledge of Space Physics, in particular regarding the characterisation of the dynamics of charged particles in space and the heliosphere. They know relevant parameters and theoretical concepts and corresponding measuring methods.

**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 can be chosen to earn a 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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Module title | Multi-wavelength Astronomy
---|---
Abbreviation | 11-MAS-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 | --

Contents
1. Phenomenology of active galactic nuclei and extragalactic jets
2. Jet-emission processes
3. VLBI observations of jets
4. High-energy observations of jets
5. Multimessenger signatures of jets

Intended learning outcomes
The students acquire knowledge of multiwavelength astronomy by studying the observations of active galactic nuclei and their extragalactic jets. They gain insights into a special, not yet solved astrophysical question and practice writing an observational proposal.

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 can be chosen to earn a 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 | Quantum Mechanics II
Abbreviation | 11-QM2-161-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) | --

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

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:

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 can be chosen to earn a 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>Managing Director of the Institute</td>
<td>Faculty of Physics and Astronomy</td>
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<td>1 semester</td>
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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 can be chosen to earn a 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>

**Contents**

In this lecture, Quantum Physics of many-particle systems are introduced on the basis of the perturbative methods of the Green's functions. A possible outline might be:

1. Single-particle Green's function
2. Review of second quantisation
3. Perturbation theory using many-particle Green's functions at temperature $T=0$
4. Perturbation theory for finite temperatures
5. Landau theory of Fermi liquids
6. Superconductivity
7. One-dimensional systems and bosonisation

**Intended learning outcomes**

The students acquire knowledge of the methods of quantum field theory in a non-relativistic context. This knowledge enables them to study properties of Fermi liquids (and bosonic systems) beyond the one-particle picture, and to understand the effects of interactions, including superconductivity and the Kondo effect.

**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 can be chosen to earn a 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 catalogue for the subject Physics

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

#### Module title

Physics of Complex Systems

#### Abbreviation

11-PKS-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. Theory of critical phenomena in thermal equilibrium  
2. Introduction into the physics out of equilibrium  
3. Entropy production and fluctuations  
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 (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 can be chosen to earn a bonus)

written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (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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### 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

The students acquire a comprehensive understanding of quantum states and density matrices beyond the usual textbook interpretation. The learn how to safely handle tensor products and multipartite quantum systems. The main topics of the lecture include basic mathematical concepts of quantum information theory and the limits 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 can be chosen to earn a 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

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 can be chosen to earn a 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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**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 can be chosen to earn a 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

This will usually be a course on quantum many particle physics using the method of functional integration. An outline could be:

1. Coherent states and review of second quantization
2. The functional integral formalism at finite temperatures $T$
3. Perturbation theory at $T=0$
4. Order parameters and broken symmetry
5. Green's functions
6. The Landau theory of Fermi liquids
7. Further developments

### Intended learning outcomes

The students are enabled to apply the modern methods of path and functional integrals to quantum many-particle systems. These methods complement the traditional methods of Green's functions and Feyman diagrams.

### Courses

<table>
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### 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)

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### Module Catalogue for the Subject Physics

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

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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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### Contents

Topologically ordered phases possess no order in the conventional sense (i.e., no broken symmetry and no local order parameter). The order is instead characterized by topological quantum numbers. In the course, the general concepts will be illustrated with the study of specific examples of systems with topological order. The topics discussed may include:

1. Fractional charge and statistics in quantized Hall fluids
2. Spin charge separation in spin chains and chiral spin liquids
3. Non-Abelian statistics of fractionalized excitations
4. Majorana zero modes in p-wave superconductors
5. Topological degeneracies on higher genus surfaces (e.g., torus geometry)
6. Spinons and visons in spin liquids including Kitaev models.

### Intended learning outcomes

The students acquire in-depth knowledge of topological order in quantum condensates.

### Courses

<table>
<thead>
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<th>(type, number of weekly contact hours, language — if other than German)</th>
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### 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)

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<table>
<thead>
<tr>
<th>Module title</th>
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<td>Topology in Solid State Physics</td>
<td>11-TFP-161-m01</td>
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<td>Faculty of Physics and Astronomy</td>
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<tr>
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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. Z2 invariants
9. Topological superconductors

### Intended learning outcomes
The students acquire a theoretical understanding of topological concepts in modern Solid-State Physics. These concepts serve as a basis of many research activities of the Faculty of Physics and Astronomy at the University of Würzburg.

### 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 can be chosen to earn a 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
Theory of Superconductivity

Abbreviation
11-TSL-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

Contents

Intended learning outcomes
This lecture focuses on the understanding of unconventional superconductivity and the interactions with magnetism in the current research context. The first part of the lecture addresses conventional molecular field theory of superconductivity (BCS theory), which fails when applied to new material classes such as high-temperature superconductors. Subsequently, it introduces tools of quantum field theory necessary to expand BCS theory. Thereby it especially focuses on Meissner effect and Higgs mechanism. The last part of the lecture discusses current developments concerning the description and analysis of (un)conventional superconductors and their fascinating connection to competing magnetic phases.

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 can be chosen to earn a 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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### Module Catalogue for the Subject

**Physics**

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

<table>
<thead>
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<th>Module title</th>
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<td>Computational Materials Science (DFT)</td>
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**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** (type, number of weekly contact hours, language — if other than German)

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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 can be chosen to earn a 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)

--
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 integration, 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 (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 can be chosen to earn a 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

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Module title | Abbreviation
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Conformal Field Theory 2 | 11-KFT2-161-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)
--- | --- | ---
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 can be chosen to earn a 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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### Module Catalogue for the Subject

**Physics**

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

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<thead>
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<th>Module title</th>
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<td>Magnetism and Spin Fluids</td>
<td>11-MSF-161-m01</td>
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</table>

### Contents

The contents of the course vary from year to year and include topics such as spin-wave theory, spin-chains, spin ladders and spin liquids with topological orders. Depending on the lecturer, the focus may lie on magnetically ordered systems or on spin liquids.

Possible topics are:

2. Magnetic order (Holstein-Primakoff bosons and spin-wave theory)
3. Valence bond solids in spin chains (Majumdar-Gosh and AKLT Models, spinon confinement and the Haldane gap)
4. Critical spin-1/2 chains (spinon excitations in the Haldane-Shastry model, holon excitations in the Kuramoto-Yokohama model)
5. Coupled spin chains and ladders
6. Chiral spin liquids (Abelian and possibly non-Abelian)
7. Kitaev’s toric code model (spinon and vison excitations)

### Intended learning outcomes

The students develop an understanding of the electronic origins of magnetism, spin-wave theory, spin-charge separation in one dimensional systems and spin-liquids as examples of systems with a topological order in two dimensions.

### 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 can be chosen to earn a 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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**Module title**  
Topological Quantum Physics  

**Abbreviation**  
11-TQP-161-m01

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**Duration**  
1 semester  

**Module level**  
graduate  

**Other prerequisites**  
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### Contents

The course is aimed at Masters students pursuing either experimental or theoretical work in their thesis. Depending on the lecturers emphasis, it is meant to provide an introduction to topological superconductors and insulators assuming only "Quantum mechanics II" (11-QM2) as a prerequisite. The contents may include:

1. Introduction to superconductivity (including BCS theory)
2. Majorana fermions and topological superconductors in 1D (Kitaev wires)
3. Topological superconductors in two dimensions (2D) (including Majorana edge states and non-Abelian statistics)
4. Integer quantum Hall effect and Chern insulators (Haldane model, Jackiw-Rebbi solitons and edge states)
5. Berry’s phase and Chern invariants
6. Time reversal symmetry and topological insulators in 2D
7. Topological insulators in 3D

### Intended learning outcomes

In-depth understanding of the topological concepts of Quantum Physics relevant to current research projects of Condensed Matter Physics at the University of Würzburg.

### 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 can be chosen to earn a 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

--

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

--
Module title: Renormalization Group and Critical Phenomena
Abbreviation: 11-CRP-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: --

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:
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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
Bosonisation and Interactions in One Dimension

### Abbreviation
11-BWW-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
--

### 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

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- Language of assessment: German and/or English

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<td>Gauge Theories</td>
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<tr>
<td>1 semester</td>
<td>graduate</td>
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</table>

**Contents**

The main topic of the course will usually be lattice gauge theories. The concepts may be taught and illustrated by elaborating on the role of lattice gauge theories in spin systems.

A possible outline might be:
1. Introduction to lattice gauge theories for spin systems
2. Phase transitions
3. The transfer matrix
4. The two-dimensional (2D) Ising model
5. Ising lattice gauge theory
6. Abelian lattice gauge theories
7. The planar Heisenberg (XY) model in 2D (Kosterlitz-Thouless transition)
8. Non-Abelian lattice gauge theories

**Intended learning outcomes**

The students acquire in-depth understanding of gauge fields in classical and Quantum Physics. They are able to apply this knowledge to spin systems, illustrating the interplay between microscopic models and field-theoretic descriptions.

**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 can be chosen to earn a 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**

--

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

--
## Module: Introduction to Gauge/Gravity Duality

**Abbreviation:** 11-GGD-161-m01

<table>
<thead>
<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
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<tr>
<td>Managing Director of the Institute of Theoretical Physics and Astrophysics</td>
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### 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** (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 can be chosen to earn a 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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Module title
Introduction to Fractional Quantisation

Abbreviation
11-EFQ-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)
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Duration
1 semester

Module level
graduate

Other prerequisites
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Contents
The course will elaborate on instances of fractional quantisation in nature, mostly employing examples from the following list:

1. Midgap states in polyacethylene
2. Abelian quantised Hall states (Laughlin states, fractional charge and statistics, hierarchy states, effective Chern-Simons theory)
3. Non-Abelian quantised Hall states (Pfaffian states, Majorana fermions, non-Abelian statistics, Read-Rezayi states)
4. Spin chains (Haldane-Shastry model, spinon excitations, holon excitations in the Kuramoto-Yokoyama model, Yangian symmetry)

Intended learning outcomes
The students become familiar with emergent phenomena in many-particle systems and with Anderson’s philosophical principle of "More is different" by studying specific examples of quantum condensates exhibiting fractional quantisation.

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

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<tr>
<th>Module title</th>
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<td>Topological Effects in Electronic Systems</td>
<td>11-TEF-161-m01</td>
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### Contents

The continuous development of the field of topological phases including topological insulators, superconductors, and spin liquids requires a continuous adaptation of the graduate curriculum. The course aims to deepen the students understanding of concepts related to contemporary research and/or to keep up with contemporary developments. The specific choice of topics will vary with the lecturers from year to year.

### Intended learning outcomes

The course offers the opportunity to get acquainted with topics of immediate relevance to research conducted at the University of Würzburg.

### Courses

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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)

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### Module title

Field Theoretical Aspects of Solid State Physics

### Abbreviation

11-FTAS-161-m01

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### Contents

The topics of the course will vary from year to year and may include the description of superconductors through classical field theory (the Higgs mechanism), non-linear sigma models for spin chains, Chern-Simons and axion theories as effective descriptions of quantised Hall fluids and topological insulators, respectively, or the SU(2) level k Wess-Zumino-Witten model as an example of a conformal field theory with a symmetry group (or algebra) beyond the Virasoro algebra.

### Intended learning outcomes

The students acquire an in-depth understanding of quantum field theory and its fundamental importance for almost all areas of Condensed Matter Physics.

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### 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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<tr>
<td>Contents</td>
<td>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.</td>
</tr>
<tr>
<td>Intended learning outcomes</td>
<td>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.</td>
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<tr>
<td>Courses</td>
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<tr>
<td>Theoretical Astrophysics</td>
<td>11-AST-161-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**
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 can be chosen to earn a 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>High Energy Astrophysics</td>
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**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 can be chosen to earn a 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>Relativistic Quantum Field Theory</td>
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**Contents**

1. Symmetries  
2. Relativistic single-particle states  
3. Lagrange formalism for fields  
4. Field quantisation  
5. Scattering theory and S-matrix  
6. Gauge principle and interaction  
7. Perturbation theory  
8. Feynman rules  
9. Quantum electrodynamic processes in Born approximation  
10. Radiative corrections  
11. 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 can be chosen to earn a 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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<tbody>
<tr>
<td>1. Generating Functionals</td>
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<td>2. Path Integrals</td>
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<td>3. Renormalization</td>
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<td>4. Renormalization group</td>
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<td>5. Gauge theories</td>
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<tr>
<td>6. Spontaneous Symmetry Breaking</td>
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<tr>
<td>7. Effective Field Theory (optional)</td>
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<tbody>
<tr>
<td>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.</td>
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<thead>
<tr>
<th>Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)</th>
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<tbody>
<tr>
<td>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).</td>
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<tr>
<td>Assessment offered: In the semester in which the course is offered and in the subsequent semester</td>
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<td>Language of assessment: German and/or English</td>
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<table>
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<table>
<thead>
<tr>
<th>Additional information</th>
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<table>
<thead>
<tr>
<th>Referred to in LPO I (examination regulations for teaching-degree programmes)</th>
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</table>
## Module Catalogue for the Subject Physics
### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Elementary Particle Physics</td>
<td>11-TEP-161-m01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managing Director of the Institute of Theoretical Physics and Astrophysics</td>
<td>Faculty of Physics and Astronomy</td>
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<table>
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<tr>
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<tr>
<td>8</td>
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<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
<td>--</td>
</tr>
</tbody>
</table>

### 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 chromodynamics
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 can be chosen to earn a 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)
--
## Selected Topics of Theoretical Elementary Particle Physics

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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</thead>
<tbody>
<tr>
<td>Selected Topics of Theoretical Elementary Particle Physics</td>
<td>11-ATTP-161-m01</td>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of weekly contact hours, language — if other than German</th>
</tr>
</thead>
<tbody>
<tr>
<td>V (3) + R (1)</td>
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</table>

Module taught in: German or English

### Method of assessment

(If other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

- written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (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

**Models Beyond the Standard Model of Elementary Particle Physics**

**Abbreviation**

11-BSM-161-m01

### Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by

Faculty of Physics and Astronomy

### ECTS

<table>
<thead>
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<tbody>
<tr>
<td>6</td>
<td>numerical grade</td>
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</tbody>
</table>

### 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 can be chosen to earn a 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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<th>Module title</th>
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<tr>
<td>Databases</td>
<td>10-I=DB-161-m01</td>
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<th>Module coordinator</th>
<th>Module offered by</th>
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<tbody>
<tr>
<td>Dean of Studies Informatik (Computer Science)</td>
<td>Institute of Computer Science</td>
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<tr>
<td>1 semester</td>
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<table>
<thead>
<tr>
<th>Contents</th>
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</thead>
<tbody>
<tr>
<td>Relational algebra and complex SQL statements; database planning and normal forms, XML data modelling; transaction management.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Intended learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The students possess knowledge about data modelling and queries in SQL, transactions as well as about easy data modelling in XML.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Courses (type, number of weekly contact hours, language — if other than German)</th>
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<tbody>
<tr>
<td>V (2) + Ü (2)</td>
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<th>Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)</th>
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<tbody>
<tr>
<td>written examination (approx. 60 to 120 minutes).</td>
</tr>
<tr>
<td>If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).</td>
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<tr>
<td>Separate written examination for Master’s students.</td>
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<tr>
<td>Language of assessment: German and/or English creditable for bonus</td>
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<thead>
<tr>
<th>Additional information</th>
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</thead>
<tbody>
<tr>
<td>Focuses available for students of the Master’s programme Informatik (Computer Science, 120 ECTS credits): SE, IS, HCI.</td>
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<tr>
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</tr>
<tr>
<td>Module title</td>
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<tr>
<td>Renormalization Group Methods in Field Theory</td>
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</table>

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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 can be chosen to earn a 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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<table>
<thead>
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<td>Introduction to Plasma Physics</td>
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<tbody>
<tr>
<td>1 semester</td>
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</table>

### 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

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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

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<table>
<thead>
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<tbody>
<tr>
<td>Computational Astrophysics</td>
<td>11-NMA-161-m01</td>
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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 can be chosen to earn a 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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## Module Catalogue for the Subject
### Physics
#### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Advanced Laboratory Course Master Part 1</td>
<td>11-P-FM1-161-m01</td>
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<table>
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<tbody>
<tr>
<td>Managing Director of the Institute of Applied Physics</td>
<td>Faculty of Physics and Astronomy</td>
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<table>
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<table>
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<th>Duration</th>
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<tbody>
<tr>
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</table>

### Contents
- Principles of Nuclear, Atomic and Molecular Physics, experiments on cryogenic temperatures and correlated systems, properties of solids, surfaces and interfaces. Experiments on the following topics: X-rays - nuclear magnetic resonance (NMR) - quantum Hall effect - optical pumping and spectroscopy in the field of optics - Hall effect - superconductivity - laser - solid-state optics

### Intended learning outcomes
- Knowledge of conducting experiments, analysing and documenting experimental results, basic knowledge of issuing scientific publications, application of modern evaluation systems. The students are familiar with modern experimental methods. They are able to work on a task on the basis of publications, to conduct and evaluate an experiment and to present and discuss their results in a scientific publication.

### Courses

<table>
<thead>
<tr>
<th>(type, number of weekly contact hours, language — if other than German)</th>
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<td>P (3)</td>
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</table>

### Method of assessment

- practical examination

Students must successfully prepare, perform, document (lab notebook) and evaluate (in the form of a scientific publication) an experiment to be considered to have successfully completed this experiment. Students must successfully complete two experiments to be considered to have successfully completed this module. Detailed regulations are laid down in the respective module description.

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 Catalogue for the Subject Physics

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

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<td>Advanced Laboratory Course Master Part 2</td>
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<tr>
<td>Managing Director of the Institute of Applied Physics</td>
<td>Faculty of Physics and Astronomy</td>
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<th>Other prerequisites</th>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
<td>Preparation and safety briefing.</td>
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</table>

### Contents

Principles of Nuclear, Atomic and Molecular Physics, experiments on cryogenic temperatures and correlated systems, properties of solids, surfaces and interfaces. Experiments on the following topics: X-rays - nuclear magnetic resonance (NMR) - quantum Hall effect - optical pumping and spectroscopy in the field of optics - Hall effect - superconductivity - laser - solid-state optics.

### Intended learning outcomes

Knowledge of conducting experiments, analysing and documenting experimental results, basic knowledge of issuing scientific publications, application of modern evaluation systems. The students are familiar with modern experimental methods. They are able to work on a task on the basis of publications, to conduct and evaluate an experiment and to present and discuss their results in a scientific publication.

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

P (3)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

**practical examination**

Students must successfully prepare, perform, document (lab notebook) and evaluate (in the form of a scientific publication) an experiment to be considered to have successfully completed this experiment. Students must successfully complete two experiments to be considered to have successfully completed this module. Detailed regulations are laid down in the respective module description.

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: Advanced Laboratory Course Master Part 3

### Abbreviation
11-P-FM3-161-m01

### Module coordinator
Managing Director of the Institute of Applied Physics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
3

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

### Duration
1 semester

### Module level
graduate

### Other prerequisites
Preparation and safety briefing.

### Contents
Principles of Nuclear, Atomic and Molecular Physics, experiments on cryogenic temperatures and correlated systems, properties of solids, surfaces and interfaces. Experiments on the following topics: X-rays - nuclear magnetic resonance (NMR) - quantum Hall effect - optical pumping and spectroscopy in the field of optics - Hall effect - superconductivity - laser - solid-state optics

### Intended learning outcomes
Knowledge of conducting experiments, analysing and documenting experimental results, basic knowledge of issuing scientific publications, application of modern evaluation systems. The students are familiar with modern experimental methods. They are able to work on a task on the basis of publications, to conduct and evaluate an experiment and to present and discuss their results in a scientific publication.

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

- P (3)

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

**practical examination**

Students must successfully prepare, perform, document (lab notebook) and evaluate (in the form of a scientific publication) an experiment to be considered to have successfully completed this experiment. Students must successfully complete two experiments to be considered to have successfully completed this module. Detailed regulations are laid down in the respective module description.

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
*Advanced Laboratory Course Master Part 4*

### Abbreviation
11-P-FM4-161-m01

### Module coordinator
Managing Director of the Institute of Applied Physics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
3

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

### Duration
1 semester

### Module level
graduate

### Other prerequisites
Preparation and safety briefing.

### Contents
Principles of Nuclear, Atomic and Molecular Physics, experiments on cryogenic temperatures and correlated systems, properties of solids, surfaces and interfaces. Experiments on the following topics: X-rays - nuclear magnetic resonance (NMR) - quantum Hall effect - optical pumping and spectroscopy in the field of optics - Hall effect - superconductivity - laser - solid-state optics

### Intended learning outcomes
Knowledge of conducting experiments, analysing and documenting experimental results, basic knowledge of issuing scientific publications, application of modern evaluation systems. The students are familiar with modern experimental methods. They are able to work on a task on the basis of publications, to conduct and evaluate an experiment and to present and discuss their results in a scientific publication.

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

P (3)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)
practical examination

Students must successfully prepare, perform, document (lab notebook) and evaluate (in the form of a scientific publication) an experiment to be considered to have successfully completed this experiment. Students must successfully complete two experiments to be considered to have successfully completed this module. Detailed regulations are laid down in the respective module description.

Language of assessment: German and/or English

### Allocation of places
--

### Additional information
--

### Referred to in LPO I (examination regulations for teaching-degree programmes)
--
### Advanced Seminar Physics A

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<tbody>
<tr>
<td>Advanced Seminar Physics A</td>
<td>11-OSP-A-161-m01</td>
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**Module coordinator**
Managing Director of the Institute of Applied Physics

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

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<td>Admission prerequisite to assessment: regular attendance (minimum 85% of sessions).</td>
</tr>
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</table>

**Duration**
1 semester

**Module level**
graduate

**Contents**
Seminar on current topics in theoretical and experimental physics

**Intended learning outcomes**
The students have advanced knowledge of a current specialist field of Experimental or Theoretical Physics. They are able to extract knowledge from professional publications and to summarise this knowledge and present it to a professional audience.

**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 can be chosen to earn a bonus)

| talk with discussion (30 to 45 minutes) |

Language of assessment: German and/or English

**Allocation of places**
--

**Additional information**
Registration: If a student registers for the seminar and obtains the qualification for admission to assessment, this will be considered a declaration of will to seek admission to assessment pursuant to Section 20 Subsection 3 Sentence 4 ASPO (general academic and examination regulations). If the module coordinators subsequently find that the student has obtained the qualification for admission to assessment, they will put the student’s registration for assessment into effect. Only those students that meet the respective prerequisites can successfully register for an assessment. Students who did not register for an assessment or whose registration for an assessment was not put into effect will not be admitted to the respective assessment. If a student takes an assessment to which he/she has not been admitted, the grade achieved in this assessment will not be considered.

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

--
Module title  |  Abbreviation
---|---
Advanced Seminar Physics B  |  11-OSP-B-161-m01

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

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

Duration  |  Module level  |  Other prerequisites
---|---|---
1 semester  |  graduate  |  Admission prerequisite to assessment: regular attendance (minimum 85% of sessions).

Contents
Seminar on current issues of Theoretical or Experimental Physics.

Intended learning outcomes
The students have advanced knowledge of a current specialist field of Experimental or Theoretical Physics. They are able to extract knowledge from professional publications and to summarise this knowledge and present it to a professional audience.

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 can be chosen to earn a bonus)
talk with discussion (30 to 45 minutes)
Language of assessment: German and/or English

Allocation of places
--

Additional information
Registration: If a student registers for the seminar and obtains the qualification for admission to assessment, this will be considered a declaration of will to seek admission to assessment pursuant to Section 20 Subsection 3 Sentence 4 ASPO (general academic and examination regulations). If the module coordinators subsequently find that the student has obtained the qualification for admission to assessment, they will put the student’s registration for assessment into effect. Only those students that meet the respective prerequisites can successfully register for an assessment. Students who did not register for an assessment or whose registration for an assessment was not put into effect will not be admitted to the respective assessment. If a student takes an assessment to which he/she has not been admitted, the grade achieved in this assessment will not be considered.

Referred to in LPO I (examination regulations for teaching-degree programmes)
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<td>Organic Semiconductors</td>
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<td>1 semester</td>
<td>graduate</td>
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</table>

### Contents

Fundamentals of organic semiconductors, molecular and polymer electronics and sensor technology, applications.

### Intended learning outcomes

The students have advanced knowledge of organic semiconductors.

### 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 can be chosen to earn a 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.

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 Catalogue for the Subject

**Physics**

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

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<td>Biophysical Measurement Technology in Medical Science</td>
<td>11-BMT-161-m01</td>
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</table>

### Contents

The lecture covers the physical principles of imaging techniques and their application in Biomedicine. The main topics are conventional X-ray technique, computer tomography, imaging techniques of nuclear medicine, ultrasound and MR-tomography. The lecture additionally addresses the systems theory of imaging systems and digital image processing.

### Intended learning outcomes

The students know the physical principles of imaging techniques and their application in Biomedicine. They understand the principles of image generation and are able to explain different techniques and interpret simple images.

### 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 can be chosen to earn a 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
---|---
Nano-Optics | 11-NOP-161-m01

Module coordinator | Module offered by
---|---
Managing Director of the Institute of Applied Physics | 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
The lecture conveys theoretical fundamentals, experimental techniques, and applications of nano-optics starting from the discussion of the focusing of light. Based on this, the fundamentals of modern far-field optical microscopy are discussed. In the following, the near-field optical microscopy is introduced and discussed. As a further basis, quantum emitters are introduced and their light emission in nano-environments is derived. Plasmons in 2D, 1D and 0 dimensions are introduced and discussed in detail. This finally leads to the concept of optical antennas.

Intended learning outcomes
The students have specific and advanced knowledge in the field of nano-optics. They are familiar with the theoretical principles and application areas of nano-optics and with current developments in this field.

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 can be chosen to earn a 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 title
Low Dimensional Structures

Abbreviation
11-NDS-161-m01

Module coordinator
Managing Director of the Institute of Applied Physics

Module offered by
Faculty of Physics and Astronomy

ECTS
6

Method of grading
Only after succ. compl. of module(s)

Duration
1 semester

Module level
graduate

Other prerequisites
Approval from examination committee required.

Contents
Low-dimensional structures: Crystal lattice symmetry. Lattice dynamics and growth techniques of low-dimensional structures. Comparison between these structures and volume solids. X-ray diffractometry. Molecular beam epitaxy.

Intended learning outcomes
The students have knowledge of the theoretical principles of the growth of low dimensional structures. They know methods of producing and analysing such structures. They know the bandstructures of the most important semiconductors as well as the fabrication and characteristics of semiconductor heterostructures and MOS-diodes. They are familiar with the subband structure of semiconductor heterostructures and MOS-diodes and can evaluate the importance of many-particle effects. They are able to solve problems related to potentials in one dimension by applying Poisson’s equation. They know the k*p perturbation theory and can deduce the 2D subband structure from the bulk band structure. They have basic knowledge of the meaning of gauging, Landau-quantisation, filling factor and Landau degeneracy. They understand how an external magnetic field acts on the properties of a free electron gas in 2D. They have basic knowledge of the meaning of modulation doping and are familiar with the 2D hydrogen atom. They understand how an external magnetic field acts on the properties of a free electron gas in 2D. They have basic knowledge of the meaning of gauging, Landau-quantisation, filling factor and Landau degeneracy. They are able to solve implicit problems via numerical methods. They are familiar with elementary excitations in two-dimensional systems.

Courses (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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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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 Catalogue for the Subject Physics

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

<table>
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<td>Superconductivity</td>
<td>11-SUP-161-m01</td>
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<td>1 semester</td>
<td>graduate</td>
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</table>

### Contents

Physical principles of superconductors and their applications (among others development of technological platforms, methods of material sciences for calculating temperature profiles in superconductors)

### Intended learning outcomes

The students have a basic understanding of superconductivity as a macroscopic quantum phenomenon. They are able to evaluate the contributions of materials sciences to the development of superconductivity.

### 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 can be chosen to earn a 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.

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>
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<td>Advanced Topics in Solid State Physics</td>
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<td>Managing Director of the Institute of Theoretical Physics and Astrophysics</td>
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</table>

**Contents**

This module will enable the lecturers of Condensed Matter Physics to teach advanced courses on topics not covered in any of the other modules. These topics may relate either to recent research developments or to subjects not included in the regular curriculum.

**Intended learning outcomes**

The students advance their knowledge and understanding of an advanced topic of Condensed Matter Physics and acquire insights into the connections between research and teaching.

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

V (3) + R (1)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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**

--

**Additional information**

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

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Module title | Abbreviation
--- | ---
Advanced Topics in Astrophysics | 11-CSAM-161-m01

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

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

| Duration | Module level | Other prerequisites |
| 1 semester | graduate | Approval from examination committee required. |

### Contents

In-depth study of particular current topics of Astrophysics. The concepts of Astrophysics which will be discussed include: Stellar structure, formation and development, radiation transport, gas dynamics, heating and cooling processes of the interstellar medium, astrochemistry, accretion and jets, galaxy formation or similar topics.

### Intended learning outcomes

The students have advanced knowledge of the subdisciplines of Astrophysics and are able to work on current scientific questions.

### Courses

| (type, number of weekly contact hours, language — if other than German) |
| V (3) + R (1) |

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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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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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### Visiting Research

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<td>chairperson of examination committee</td>
<td>Faculty of Physics and Astronomy</td>
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<td></td>
<td>graduate</td>
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</table>

### Contents

Independent work on a current research topic of Experimental and Theoretical Physics. Implementation of scientific experiments including analysis and documentation of the results, especially in the context of research visits to other universities or research institutes.

### Intended learning outcomes

The students are able to independently work on a current research area of Experimental or Theoretical Physics, to conduct and analyse scientific experiments and to document the results.

### Courses

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<th>type, number of weekly contact hours, language — if other than German</th>
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</table>

### Method of assessment

- project report (10 to 20 pages)
- 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
---|---
Current Topics in Experimental Physics | 11-EXE5-161-m01

Module coordinator | Module offered by
---|---
chairperson of examination committee | Faculty of Physics and Astronomy

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

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | Approval from examination committee required.

Contents
Current topics in experimental 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 Experimental Physics of the Master's programme. They have knowledge of a current subdiscipline of Experimental Physics and understand the measuring and/or evaluation 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 can be chosen to earn a 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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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: Current Topics in Experimental Physics  
Abbreviation: 11-EXE6-161-m01

Module coordinator: chairperson of examination committee

Module offered by: Faculty of Physics and Astronomy

ECTS: 6

Method of grading: numerical grade

Duration: 1 semester

Module level: graduate

Other prerequisites: Approval from examination committee required.

Contents:
Current topics in experimental 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 Experimental Physics of the Master’s programme. They have knowledge of a current subdiscipline of Experimental Physics and understand the measuring and/or evaluation 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).

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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 coordinator**
chairperson of examination committee

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

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**Contents**

Current topics in Experimental 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 Experimental Physics of the Master's programme. They have knowledge of a current subdiscipline of Experimental Physics and understand the measuring and/or evaluation 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 (3) + R (1)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

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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**

Current topics in experimental 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 Experimental Physics of the Master’s programme. They have knowledge of a current subdiscipline of Experimental Physics and understand the measuring and/or evaluation 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 can be chosen to earn a 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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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 | Current Topics in Experimental Physics
---|---
Abbreviation | 11-EXE6A-161-m01
Module coordinator | chairperson of examination committee
Module offered by | Faculty of Physics and Astronomy
ECTS | 6
Method of grading | numerical grade
Duration | 1 semester
Module level | graduate
Other prerequisites | Approval from examination committee required.
Contents
Current topics in experimental 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 Experimental Physics of the Master’s programme. They have knowledge of a current subdiscipline of Experimental Physics and understand the measuring and/or evaluation 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).
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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 Catalogue for the Subject Physics

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

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### Contents

Current topics in experimental or theoretical 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 Experimental or Theoretical Physics of the Master's programme of Nanostructure Technology. They have knowledge of a current subdiscipline of Physics and understand the measuring and/or calculation 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)

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### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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)

--
# Thermodynamics and Economics

**Module title**  
Thermodynamics and Economics

**Abbreviation**  
11-TDO-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**  
Only after succ. compl. of module(s)

**Duration**  
1 semester

**Module level**  
graduate

**Other prerequisites**  
--

## Contents

Energy and economic growth, entropy production, emission reduction.

Part I describes the role of energy conversion in the development of the universe, the evolution of life and the unfolding of civilisation. The density of entropy production of non-equilibrium thermodynamics shows the significance of the second law of thermodynamics for ecological damage and resource consumption. Energy conversion, entropy production and natural resources define the technological and ecological boundaries of industrial economic growth.

Part 2 analyses how the factors capital, work, energy and creativity produce the goods and services of a national economy and determine economic growth. The productive power of cheap energy far exceeds that of expensive labour. Within the current system of taxes and social security contributions, this discrepancy between power and costs of production factors leads to job cuts, waste of resources, impoverishment of nations and growing social tensions. The course discusses how factor income taxation can counteract this development.

Part 3 includes seminar presentations, comprises the techniques of rational energy use and non-fossil energy use, and introduces the optimisation programme deeco (Dynamic Energy, Emission and Cost Optimization).

## Intended learning outcomes

The students understand that energy conversion and entropy production are going to play an important role in the world’s economic and social development. As an extension of economic theory, the students know the connections between thermodynamics and economy as well as the productive physical basis of modern economies. They are able to apply the acquired knowledge to particular problems.

NOTE: this is the module that was run by Prof. Dr. R. Kümmel, who has now retired. As the module was tailored to his own theory of economy, it has yet to be decided whether we will continue to offer this module.

## Courses

**Type, number of weekly contact hours, language**  
V (3) + R (1)

Module taught in: German or English

## Method of assessment

**Type, scope, language**  
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.

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

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

--
Module title
Current Topics of Theoretical Physics

Abbreviation
11-EXT5-161-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 Theoretical 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 Theoretical Physics of the Master's programme. They have advanced specialist knowledge of a subdiscipline of Theoretical Physics and have mastered the required methods. They are able to apply the acquired methods to current problems of Theoretical Physics.

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 can be chosen to earn a 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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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 Catalogue for the Subject Physics**  
**Master's with 1 major, 120 ECTS credits**

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**Contents**

Current topics in theoretical 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 Theoretical Physics of the Master's programme. They have advanced specialist knowledge of a subdiscipline of Theoretical Physics and have mastered the required methods. They are able to apply the acquired methods to current problems of Theoretical Physics.

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

V (3) + R (1)

**Method of assessment**  
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

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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
---|---
Current Topics of Theoretical Physics | 11-EXT7-161-m01

Module coordinator | Module offered by
chairperson of examination committee | Faculty of Physics and Astronomy

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Contents

Current topics in Theoretical 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 Theoretical Physics of the Master’s programme. They have advanced specialist knowledge of a subdiscipline of Theoretical Physics and have mastered the required methods. They are able to apply the acquired methods to current problems of Theoretical Physics.

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

V (3) + R (1)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

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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)

--
## Current Topics of Theoretical Physics

**Module title**  
Current Topics of Theoretical Physics

**Abbreviation**  
11-EXT8-161-m01

**Module coordinator**  
chairperson of examination committee

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

**ECTS**  
8

**Method of grading**  
numerical grade

**Duration**  
1 semester

**Module level**  
graduate

**Other prerequisites**  
Approval from examination committee required.

### Contents

Current topics in Theoretical 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 Theoretical Physics of the Master's programme. They have advanced specialist knowledge of a subdiscipline of Theoretical Physics and have mastered the required methods. They are able to apply the acquired methods to current problems of Theoretical Physics.

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### Method of assessment

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### Contents

Current topics in Theoretical 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 Theoretical Physics of the Master's programme. They have advanced specialist knowledge of a subdiscipline of Theoretical Physics and have mastered the required methods. They are able to apply the acquired methods to current problems of Theoretical Physics.

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

| V (3) + R (1) |

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

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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: Current Topics in Physik
Abbreviation: 11-EXP6A-161-m01

Module coordinator: chairperson of examination committee
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: Approval from examination committee required.

Contents
Current topics in Experimental or Theoretical 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 Experimental or Theoretical Physics of the Master's programme of Nanostructure Technology. They have knowledge of a current subdiscipline of Physics and understand the measuring and/or calculation 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 (3) + R (1)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

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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>Sensor and Actor Materials - Functional Ceramics and Magnetic Particles</td>
<td>08-FU-SAM-161-m01</td>
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<thead>
<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
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<tbody>
<tr>
<td>degree programme coordinator Funktionswerkstoffe (Functional Materials)</td>
<td>Chair of Chemical Technology of Material Synthesis</td>
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<tbody>
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<td>1 semester</td>
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**Contents**

German contents available but not translated yet.


**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Der/Die Studierende verfügt über grundlegende Kenntnisse im Bereich der sensorischen und aktorischen Materialien.

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

V (2) + P (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, approx. 30 minutes per candidate)

Assessment offered: Once a year, summer semester

Language of assessment: German and/or English

P: 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>Structure and Properties of Modern Materials: Experiments vs. Simulations</td>
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**Module coordinator**  
degree programme coordinator Funktionswerkstoffe (Functional Materials)  
**Module offered by**  
Chair of Chemical Technology of Material Synthesis

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**Duration**  
1 semester  
**Module level**  
graduate  
**Other prerequisites**  
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**Contents**

German contents available but not translated yet.


**Intended learning outcomes**

German intended learning outcomes available but not translated yet.


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

V (2) + S (1)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

a) talk (approx. 30 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups of 2 (approx. 30 minutes total)  
Assessment offered: Once a year, winter 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
Nonphysical Minor Subject

### Abbreviation
11-EXNP6-161-m01

### Module coordinator
chairperson of examination committee

### 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
Approval from examination committee required.

### Contents
Non-technical minor. Crediting for academic achievements, e.g. from university change or study abroad

### Intended learning outcomes
The students have advanced competencies on the Master's level which correspond to the requirements of a module in the field of a non-physical minor (mathematics, chemistry, informatics...).

### Courses (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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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<tr>
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<td>graduate</td>
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</table>

**Contents**

Introduction to current experimental or theoretical questions of a subdiscipline of Physics with special relevance to the planned topic of the Master's thesis. Summary of the required fundamental topics in a seminar presentation.

**Intended learning outcomes**

The students have advanced knowledge of a current experimental or theoretical subdiscipline of 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 (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 can be chosen to earn a bonus)

talk with discussion (30 to 45 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>Scientific Methods and Project Management Physics</td>
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### Contents

Introduction to the methods of scientific work, taking into account methods of project planning. Application to theoretical and experimental questions of 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 experimental and theoretical subdiscipline of 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 experimental or theoretical work. They are able to describe their projects in oral presentations.

### Courses

<table>
<thead>
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Module taught in: German or English

### Method of assessment

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<tr>
<td>talk with discussion (30 to 45 minutes)</td>
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Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO 1 (examination regulations for teaching-degree programmes)

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<table>
<thead>
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<td>Master Thesis Physics</td>
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</table>

**Contents**

Independent work on an experimental or theoretical research task within physics, in particular using state-of-the-art methods and according to scientific aspects. Writing of the master thesis.

**Intended learning outcomes**

The students are able to independently work on an experimental or theoretical task from Physics, especially according to known methods and scientific aspects and to summarise their results in a final paper.

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

No courses assigned to module

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus)

Master's thesis (750 to 900 hours total)
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
---|---
Advanced Magnetic Resonance Imaging | 11-MRI-171-m01

| Module coordinator | Module offered by |
---|---|
Managing Director of the Institute of Applied Physics | 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

Nuclear magnetic resonance (NMR) is a quantum mechanical phenomenon that, through magnetic resonance imaging (MRI), has played a major role in the revolution of medical imaging over the last 30 years. Based on the fundamental principles of nuclear magnetic resonance (resonance principle, relaxation times, chemical shift) this course covers:

1) the NMR signal theory and signal evolution (Bloch equations),
2) the principles of spatial encoding, magnetic resonance imaging (MRI) and corresponding imaging sequences and measurement parameters,
3) the concept of k-space and Fourier imaging, and
4) the physical, methodological and technical possibilities and limits of MRI. As a last point, exemplary applications of MRI of biomedical research, clinical imaging and non-destructive testing are introduced.

Intended learning outcomes

The students have advanced knowledge of the mathematical-theoretical and physical principles of modern imaging magnetic resonance, image generation and processing. They gain a broad overview of the field of modern MRI and its interdisciplinary contexts and applications.

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

V (3) + R (1)
Module taught in: English
In the semester in which the course is offered and in the subsequent semester

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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 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
Only after succ. compl. of module(s)

### Duration
1 semester

### Module level
graduate

### Other prerequisites
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### 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 can be chosen to earn a 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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### String Theory 2

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

**Numerical grade**
--

**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
--

### 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
**Module taught in:** German or English

**V (3) + R (1)**

### Method of assessment
**Type,** scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a bonus

- a) written examination (approx. 90 to 120 minutes) or
- b) oral examination of one candidate each (approx. 30 minutes) or
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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**
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<td>Surface Science</td>
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<tbody>
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### Contents


### Intended learning outcomes

The students have gained an overview of the diverse aspects of surface physics and especially know the causes and contexts of physical peculiarities of surfaces and interfaces. Additionally, they know the most important experimental techniques and their specific application possibilities in the context of surface physics.

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

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<thead>
<tr>
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<th>Language</th>
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Module taught in: Englisch

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module can be chosen to earn a 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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