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

Examination regulations version: 2020
Responsible: Faculty of Mathematics and Computer Science
Responsible: Institute of Mathematics
Responsible: Faculty of Physics and Astronomy
## Contents

The subject is divided into

### Learning Outcomes

### Abbreviations used, Conventions, Notes, In accordance with

### Compulsory Courses

#### Subfield Analysis
- Overview Analysis for Mathematical Physics
- Advanced Analysis

#### Subfield Linear Algebra
- Overview Linear Algebra for Mathematical Physics

#### Subfield Classical Physics
- Classical Physics 1 (Mechanics)
- Classical Physics 2 (Heat and Electromagnetism)

#### Subfield Theoretical Mechanics and Quantum Mechanics
- Theoretical Mechanics
- Quantum Mechanics

#### Subfield Statistical Physics and Electrodynamics
- Statistical Physics and Electrodynamics
- Statistical Physics - Exercises
- Electrodynamics - Exercises

#### Subfield Laboratory Course Physics
- Laboratory Course Physics A (Mechanics, Heat, Electromagnetism)
- Data and Error Analysis
- Laboratory Course Physics B for Students of Mathematical Physics
- Laboratory Course Physics C for Students of Mathematical Physics
- Advanced and Computational Data Analysis

### Compulsory Electives Analysis and Linear Algebra

#### Subgroup Basics of Mathematical Methods
- Analysis 1 for Mathematical Physics
- Analysis 2 for Mathematical Physics

#### Subfield Lineare Algebra
- Linear Algebra 1 for Mathematical Physics
- Linear Algebra 2 for Mathematical Physics

### Mathematical Methods

#### Subgroup Basics of Mathematical Methods
- Introduction to Differential Geometry
- Ordinary Differential Equations
- Introduction to Complex Analysis
- Geometric Analysis
- Introduction to Functional Analysis
- Introduction to Partial Differential Equations

### Subfield Overview Mathematical Methods
- Overview Differential Geometry and Ordinary Differential Equations for Mathematical Physics
- Overview Complex Analysis and Differential Geometry for Mathematical Physics
- Overview Complex Analysis and Ordinary Differential Equations for Mathematical Physics
- Overview Geometric Analysis and Differential Geometry for Mathematical Physics
- Overview Geometric Analysis and Ordinary Differential Equations for Mathematical Physics
- Overview Geometric Analysis and Complex Analysis for Mathematical Physics
- Overview Functional Analysis and Differential Geometry for Mathematical Physics
- Overview Functional Analysis and Ordinary Differential Equations for Mathematical Physics
- Overview Functional Analysis and Complex Analysis for Mathematical Physics
Overview Functional Analysis and Geometric Analysis for Mathematical Physics  
Overview Differential Geometry and Partial Differential Equations for Mathematical Physics  
Overview Ordinary Differential Equations and Partial Differential Equations for Mathematical Physics  
Overview Complex Analysis and Partial Differential Equations for Mathematical Physics  
Overview Geometric Analysis and Partial Differential Equations for Mathematical Physics  
Overview Functional Analysis and Partial Differential Equations for Mathematical Physics  

Mathematical Physics  

Module Group Supplementary Topics in Mathematics  
Numerical Mathematics 1 for Mathematical Physics  
Numerical Mathematics 2 for Mathematical Physics  
Stochastics 1 for Mathematical Physics  
Stochastics 2 for Mathematical Physics  
Introduction to Algebra for Mathematical Physics  
Introduction to Discrete Mathematics for Mathematical Physics  
Introduction to Projective Geometry for Mathematical Physics  
Introduction to Number Theory for Mathematical Physics  
Operations Research for Mathematical Physics  
Introduction to Differential Geometry for Mathematical Physics  
Ordinary Differential Equations for Mathematical Physics  
Introduction to Complex Analysis for Mathematical Physics  
Geometric Analysis for Mathematical Physics  
Introduction to Functional Analysis for Mathematical Physics  
Introduction to Partial Differential Equations for Mathematical Physics  

Module Group Experimental Physics  
Optics and Waves  
Atoms and Quanta  
Introduction to Solid State Physics  
Nuclear and Elementary Particle Physics  

Module Group Supplementary Topics in Physics  
Introduction to Relativistic Physics and Classical Field Theory  
Introduction to Quantum Computing and Quantum Information  
Group Theory  
Quantum Field Theory I  
Computational Physics  
Statistics, Data Analysis and Computer Physics  
Astrophysics  
Particle Physics (Standard Model)  

Module Group Current Topics in Mathematical Physics  
Current Topics in Mathematical Physics  
Current Topics in Mathematical Physics  
Current Topics in Mathematical Physics  

Key Skills Area  

General Key Skills  

General Key Skills (subject-specific)  
Exercise tutor or proof-reading in Mathematics  
E-Learning and Blended Learning Mathematics 1  
E-Learning und Blended Learning Mathematik 2  
MINT Preparatory Course Mathematical Methods of Physics  

Subject-specific Key Skills  

Compulsory Courses  
Basic Notions and Methods of Mathematical Reasoning  
Reasoning and Writing in Mathematics  
Seminar Mathematical Physics  

Bachelor's with 1 major Mathematical Physics  
(2020)
Module Catalogue for the Subject
Mathematical Physics
Bachelor’s with 1 major, 180 ECTS credits

Subject-specific Key Skills, Compulsory Electives

Supplementary Seminar Mathematics
Seminar Experimental/Theoretical Physics
Introduction to Topology
Computational Mathematics
Programming course for students of Mathematics and other subjects
Selected Topics in History of Mathematics
Mathematical Writing
School Mathematics from a Higher Perspective
Proseminar Mathematics
Mathematical Methods of Physics
Computational Physics

Thesis

Bachelor Thesis Mathematical Physics
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Learning Outcomes

German contents and learning outcome available but not translated yet.

Wissenschaftliche Befähigung

- Die Absolventinnen und Absolventen sind vertraut mit den Arbeitsweisen und der zugehörigen Fachsprache der Mathematik und beherrschen die Methoden mathematischen Denkens und Beweisens.
- Die Absolventinnen und Absolventen besitzen Kenntnisse mathematischer Grundlagen der Theoretischen Physik und sind vertraut mit den grundlegenden Beweismethoden dieser Gebiete.
- Die Absolventinnen und Absolventen verstehen die mathematischen, theoretischen und experimentellen Grundlagen der Physik und können diese anwenden.
- Die Absolventinnen und Absolventen können unter Anleitung Experimente durchführen, analysieren und die erhaltenen Ergebnisse darstellen und bewerten.
- Die Absolventinnen und Absolventen sind in der Lage, physikalische Probleme durch Anwendung der wissenschaftlichen Arbeitsweise und unter Beachtung der Regeln guter wissenschaftlicher Praxis (Dokumentation, Fehleranalyse) zu bearbeiten.
- Die Absolventinnen und Absolventen verstehen die wesentlichen Zusammenhänge und Konzepte der einzelnen Teilgebiete der Theoretischen Physik.
- Die Absolventinnen und Absolventen sind in der Lage, ihre mathematischen Fähigkeiten auf physikalische Fragestellungen anzuwenden.
- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein hohes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, sich selbständig mithilfe von Fachliteratur in weitere Gebiete der Mathematik und Physik einzuarbeiten.
- Die Absolventinnen und Absolventen sind in der Lage, ihre Kenntnisse, Ideen und Problemlösungen verständlich zu präsentieren.
- Die Absolventinnen und Absolventen besitzen die für ein weiterführendes, insbesondere Master-Studium in Mathematik und Physik, erforderlichen Grundkenntnisse, Denk- und Arbeitsweisen und Methodenkenntnisse.
- Die Absolventinnen und Absolventen kennen die Regeln guter wissenschaftlicher Praxis und sind in der Lage, sie in ihrer eigenen Arbeit zu beachten.

Befähigung zur Aufnahme einer Erwerbstätigkeit

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein hohes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, konkrete Probleme zu erkennen, strukturieren und modellieren und mit mathematischen und physikalischen Methoden Lösungswege zu entwickeln.
- Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
- Die Absolventinnen und Absolventen sind in der Lage, sich weitere Wissensgebiete selbständig, effizient und systematisch zu erschließen.
- Die Absolventinnen und Absolventen sind in der Lage, konstruktiv und zielorientiert in einem heterogenen, interdisziplinären Team zusammenzuarbeiten, unterschiedliche und abweichen-
...de Ansichten produktiv zur Zielerreichung zu nutzen und auftretende Konflikte zu lösen (Teamfähigkeit).

- Die Absolventinnen und Absolventen sind in der Lage, Daten mit Hilfe von statistischen Methoden zu analysieren, zu interpretieren und darzustellen.

Persönlichkeitsentwicklung

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein hohes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen kennen die Regeln guter wissenschaftlicher Praxis und sind in der Lage, sie in ihrer eigenen Arbeit zu beachten.
- Die Absolventinnen und Absolventen sind in der Lage, gesellschaftliche, wirtschaftliche und historische Entwicklungen und Prozesse kritisch zu reflektieren und zu bewerten.
- Die Absolventinnen und Absolventen entwickeln die Bereitschaft und Fähigkeit, ihre Kompetenzen in partizipative Prozesse einzubringen und aktiv an Entscheidungen mitzuwirken.
- Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
- Die Absolventinnen und Absolventen sind in der Lage, Ideen und Lösungsvorschläge allgemeinverständlich zu formulieren und präsentieren.
Abbreviations used

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

Term: SS = summer semester, WS = winter semester

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

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

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

Conventions

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

Notes

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

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

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

In accordance with

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

ASPO2015

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

22-Jan-2020 (2020-6)

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

(104 ECTS credits)
Subfield Analysis
(25 ECTS credits)
<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Overview Analysis for Mathematical Physics</td>
<td>10-M-ANP-Ü-202-m01</td>
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</table>

- **Module coordinator**: Dean of Studies Mathematik (Mathematics)
- **Module offered by**: Institute of Mathematics
- **ECTS**: 16
- **Method of grading**: numerical grade
- **Duration**: 2 semester
- **Module level**: undergraduate
- **Other prerequisites**: --

### Contents
- Real numbers and completeness; complex numbers; basic topological notions; convergence and divergence of sequences and series; power series and Taylor series; basics in differential calculus in one variable; basics of integral calculus in one variable (Riemann integral and improper integral).
- Further topological considerations, normed and metric spaces; basics in differential calculus in several variables, Taylor’s theorem for multivariate functions, Banach’s fixed point theorem; inverse function theorem, implicit function theorem.

### Intended learning outcomes
The student knows and masters the essential methods and proof techniques of analysis and is able to apply them independently, He/She has an overview over the fundamental notions and concepts of analysis, their analytic background and geometric interpretation, and can interconnect them and express them adequately in written and oral form.

### Courses
- **V (4) + V (4) + Ü (2)**

### Method of assessment
- **oral examination of one candidate each (20 to 40 minutes)**
- Language of assessment: German and/or English

### Allocation of places
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### Additional information
- Assessment will have reference to the contents of modules 10-M-ANAP1 and 10-M-ANAP2.
- Referred to in LPO I (examination regulations for teaching-degree programmes)
<table>
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<th>Module title</th>
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<tr>
<td>Advanced Analysis</td>
<td>10-M-VAN-202-m01</td>
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<table>
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<tr>
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<th>Module offered by</th>
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<tr>
<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<table>
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<tr>
<th>ECTS</th>
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<td>9</td>
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<th>Duration</th>
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<th>Other prerequisites</th>
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<tr>
<td>1 semester</td>
<td>undergraduate</td>
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### Contents

Continuation of analysis in several variables; Lebesgue measure and Lebesgue integral in $\mathbb{R}^n$, integral 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 is creditable for 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) creditable for bonus

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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Subfield Linear Algebra

(16 ECTS credits)
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<td>Overview Linear Algebra for Mathematical Physics</td>
<td>10-M-LNP-Ü-202-m01</td>
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<th>Module coordinator</th>
<th>Module offered by</th>
</tr>
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<tbody>
<tr>
<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<th>ECTS</th>
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<tr>
<td>16</td>
<td>numerical grade</td>
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<table>
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<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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<tr>
<td>2 semester</td>
<td>undergraduate</td>
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**Contents**

Basic notions and structures: groups, rings, fields, polynomials; matrices: Gauß algorithm, echolon form, rank; vector spaces over arbitrary fields: linear independance, basis, dimension, coordinates, change of basis, sums, direct sums and quotients of subspaces, linear maps, kernel and image, dimension theorem, matrix representation, determinants. Eigenvalue theory: characteristic polynomial, Caley-Hamilton theorem, minimal polynomial, invariant subspaces, diagonalisability, nilpotent maps, Jordan normal form; Euclidean/unitary spaces: scalar product, orthonormal bases, orthogonal complement, orthogonal/unitary matrices, selfadjoint and normal matrices, positive definit matrices.

**Intended learning outcomes**

The student knows and masters the essential methods and proof techniques of linear algebra and is able to apply them independently. He/She has an overview over the fundamental notions and methods of linear algebra, knows about their algebraic and geometric background, is able to relate them to each other and can present them adequately in written and oral form.

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

V (4) + V (4) + Ü (2)

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

oral examination of one candidate each (20 to 40 minutes)
Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

Assessment will have reference to the contents of modules 10-M-LNAP1 and 10-M-LNP-Ü.

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

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Subfield Classical Physics
(16 ECTS credits)
Module Catalogue for the Subject
Mathematical Physics
Bachelor's with 1 major, 180 ECTS credits

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<td>11-E-M-152-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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<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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<tr>
<td>1 semester</td>
<td>undergraduate</td>
<td>Admission prerequisite to assessment: completion of exercises (approx. 13 exercise sheets per semester). Students who successfully completed approx. 50% of exercises will qualify for admission to assessment. The lecturer will inform students about the respective details at the beginning of the semester.</td>
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Contents

1. Principles: Physical quantities, prefactors, derived quantities, dimensional analysis, time / length / mass (definition, measurement procedures, SI), importance of metrology;
2. Point Mechanics: Kinematics, motion in 2D and 3D / vectors, special cases: Uniform and constant accelerated motion, free fall, slate litter; circular motion in polar coordinates;
3. Newton’s laws: Forces and momentum definition, weight vs. mass forces on the pendulum, forces on an atomic scale, isotropic and anisotropic friction. Preparation of the equations of motion and solutions;
4. Work and energy: (Kinetic) performance, examples;
5. Elastic, inelastic and super-elastic collision: Energy and momentum conservation, surges in centre of mass and balance system, rocket equation;
6. Conservative and non-conservative force fields: Potential, potential energy; law, weight scale, field strength and potential of gravity (general relations);
7. Rotational motion: Angular momentum, angular velocity, torque, rotational energy, moment of inertia, analogies to linear translation, applications, satellites (geostationary and interstellar), escape velocities, trajectories in the central potential;
8. Tidal forces: Inertial system, reference systems, apparent forces, Foucault pendulum, Coriolis force, centrifugal force;
9. Galilean transformation: Brief digression to Maxwell’s equations, ether, Michelson interferometer, Einstein’s postulates, problem of simultaneity, Lorentz transformation, time dilation and length contraction, relativistic impulse;
10. Rigid body and gyroscope: Determining the centre of mass, inertia tensor and -ellipsoid, principal axes and their stability, tensor on the example of the elasticity tensor, physics of the bike; gyroscope: Precession and nutation, the Earth as a spinning top;
11. Friction: Static and dynamic friction, stick-slip motion, rolling friction, viscous friction, laminar flow, eddy formation;
12. Vibration: Representation by means of complex e-function, equation of motion (DGL) on forces, torque and power approach, Taylor expansion, harmonic approximation; spring and pendulum, physical pendulum, damped vibration (resonant case, Kriechfall, aperiodic limit), forced vibration, Fourier analysis;
13. Coupled vibrations: Eigenvalues and eigenfunctions, double pendulum, deterministic vs. chaotic motion, non-linear dynamics and chaos;
14. Waves: Wave equation, transverse and longitudinal waves, polarisation, principle of superposition, reflection at the open and closed end, speed of sound; interference, Doppler effect; phase and group velocity, dispersion relation;
15. Elastic deformation of solid bodies: Elastic modulus, general Hooke’s law, elastic waves;
16. Fluids: Hydrostatic pressure and buoyancy, surface tension and contact angle, capillary forces, steady flows, Bernoulli equation; Boyle-Mariotte, gas laws, barometric height formula, air pressure, compressibility and compressive modulus;
17. Kinetic theory of gases: ideal and real gas, averages, distribution functions, equipartition theorem, Brownian motion, collision cross section, mean free path, diffusion and osmosis, degrees of freedom, specific heat
### Intended learning outcomes

The students understand the basic contexts and principles of mechanics, vibration, waves and kinetic theory of gases. They are able to apply mathematical methods to the formulation of physical contexts and autonomously apply their knowledge to the solution of mathematical-physical tasks.

### Courses

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<tr>
<th>Type</th>
<th>Number of weekly contact hours</th>
<th>Language</th>
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<td>V (4)</td>
<td>+ Ü (2)</td>
<td>German or English</td>
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</table>

Module taught in: Ü: German or English

### Method of assessment

<table>
<thead>
<tr>
<th>Type</th>
<th>Scope</th>
<th>Language</th>
<th>Examination offered</th>
<th>Information on whether module is creditable for bonus</th>
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<tr>
<td>written examination</td>
<td>(approx. 120 minutes)</td>
<td>German and/or English</td>
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</tbody>
</table>

### Allocation of places

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### Additional information

Registration: If a student registers for the exercises 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

§ 53 I Nr. 1 a)
§ 77 I Nr. 1 a)
Module title | Abbreviation
--- | ---
Classical Physics 2 (Heat and Electromagnetism) | 11-E-E-152-m01

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

<table>
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<th>ECTS</th>
<th>Method of grading</th>
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<tbody>
<tr>
<td>8</td>
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</tbody>
</table>

Duration | Module level | Other prerequisites
1 semester | undergraduate | Admission prerequisite to assessment: completion of exercises (approx. 13 exercise sheets per semester). Students who successfully completed approx. 50% of exercises will qualify for admission to assessment. The lecturer will inform students about the respective details at the beginning of the semester.

Contents
1. Thermodynamics (linked to 11-E-M); temperature and quantity of heat, thermometer, Kelvin scale;
2. Heat conduction, heat transfer, diffusion, convection, radiant heat;
3. Fundamental theorems of thermodynamics, entropy, irreversibility, Maxwell’s demon;
4. Heat engines, working diagrams, efficiency, example: Stirling engine;
5. Real gases and liquids, states of matter (also solids), van der Waals, critical point, phase transitions, critical phenomena (opalescence), coexistence region, Joule-Thomson;
6. Electrostatics, basic concepts: Electrical charge, forces; electric field, reps. field concept, field lines, field of a point charge;
7. Gaussian sentence, related to Coulomb’s law, definition of "river"; Gaussian surface, divergence theorem; special symmetries; divergence and GS in differential form;
8. Electrical potential, working in the E-box, electric. potential, potential difference, voltage; potential equation, equipotential surfaces; several important examples: Sphere, hollow sphere, capacitor plates, electric dipole; lage effects, Segner wheel;
9. Matter in the E-field, charge in a homogeneous field, Millikan experiment, Braun tube; electron: Field emission, thermionic emission, dipole in homogeneous and inhomogeneous field; induction, Faraday cage;
10. Capacitor, mirror charge, definition, capacity; plate and spherical capacitor; combination of capacitors; media in the capacitor; electrical polarisation, displacement and orientation polarisation, microscopic image; dielectric displacement; electrolytic capacitor; Piezoelectric effect;
11. Electricity, introduction, current density, drift velocity, conduction mechanisms;
12. Resistance and conductivity, resistivity, temperature dependence; Ohm’s law; realisations (resistive and non-ohmic, NTC, PTC);
13. Circuits, electrical networks, Kirchhoff’s rules (meshes, nodes); internal resistance of a voltage source, measuring instruments; Wheatstone bridge;
14. Power and energy in the circuit; Capacitor charge; galvanic element; thermovoltage;
15. Transfer mechanisms, conduction in solids: Band model, semiconductor; line in liquids and gases;
16. Magnetostatics, fundamental laws; permanent magnet, field properties, definitions and units; Earth’s magnetic field; Amper’s Law, analogous to e-box, magn. river, swirl;
17. Vector potential, formal derivation, analogous to electric scalar potential; calculation of fields, examples, Helmholz coils;
18. Moving charge in the static magnetic field, current balance, Lorentz force, right-hand rule, electric motor; dipole field; movement paths, mass spectrometer, Wien filters, Hall effect; electron: e / m determination;
19. matter in the magnetic field, effects of the field on matter, relative permeability, susceptibility; para-, dia-, ferromagnetism; magn. moment of the electron, behaviour at interfaces;
20. induction, Faraday’s law of induction, Lenz’s rule, flux change, eddy electric field, Waltenhofen’s pendulum; inductance,self-induction; applications: Transformer, generator;
21. Maxwell’s displacement current, choice of integration area, displacement current; Maxwell’s extension, wave equation; Maxwell equations;
22. AC: Fundamentals, sinusoidal vibrations, amplitude, period and phase; power and RMS value, ohmic resistance; Capacitive & inductive resistor, capacitor and coil, phase shift and frequency dependence; impedance: Complex resistance; performance of the AC;
23. Resonant circuits, combinations of RLC; series and parallel resonant circuit; forced vibration, damped harmonic oscillator (related to 11-E-M);
24: Hertz dipole, characteristics of irradiation, near field, far field; Rayleigh scattering; accelerated charge, synchrotron radiation, X-rays; 25. Electromagnetic waves: Principles, Maxwell’s determination to electromagnetism, radiation pressure (Poynting vector, radiation pressure).

**Intended learning outcomes**
The students understand the basic principles and contexts of thermodynamics, science of electricity and magnetism. They know relevant experiments to observe and measure these principles and contexts. They are able to apply mathematical methods to the formulation of physical contexts and autonomously apply their knowledge to the solution of mathematical-physical tasks.

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

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 120 minutes)
Language of assessment: German and/or English

**Allocation of places**
--

**Additional information**
Registration: If a student registers for the exercises 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)
§ 53 I Nr. 1 a)
§ 77 I Nr. 1 a)
**Subfield Theoretical Mechanics and Quantum Mechanics**

(16 ECTS credits)
Module title | Abbreviation
--- | ---
Theoretical Mechanics | 11-T-M-152-m01

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

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

<table>
<thead>
<tr>
<th>ECTS</th>
<th>Method of grading</th>
<th>Only after succ. compl. of module(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>numerical grade</td>
<td>--</td>
</tr>
</tbody>
</table>

**Duration**
1 semester

**ECTS** 8

**Module level**
undergraduate

**Other prerequisites**
Admission prerequisite to assessment: completion of exercises (approx. 13 exercise sheets per semester). Students who successfully completed approx. 50% of exercises will qualify for admission to assessment. The lecturer will inform students about the respective details at the beginning of the semester.

**Contents**

1. Newton’s formulation: Inertial systems, Newton’s laws of motion, equations of motion; one-dimensional motion, energy conservation; Harmonic oscillator; Movement in space of intuition, conservative forces;
2. Lagrangian formulation: Variational principles, Euler-Lagrange equation; constraints; coordinate transformations, mechanical gauge transformation; symmetries, Noether theorem, cyclic coordinates; accelerated reference systems and apparent forces;
3. Hamiltonian formulation: Legendre transformation, phase space; Hamilton function, canonical equations; Poisson brackets, canonical transformations; generator of symmetries, conservation laws; minimal coupling; Liouville theorem; Hamilton-Jacobi formulation [optional];
4. Applications: Central-force problems; mechanical similarity, Virial theorem; minor vibrations; particles in an electromagnetic field; rigid bodies, torque and inertia tensor, centrifugal and Euler equations [optional]; scattering, cross section [optional];
5. Relativistic dynamics: Lorentz Transformation; Minkowski space; equations of motion; 6. Non-linear dynamics: Stability theory; KAM theory [optional]; deterministic chaos [optional];

**Intended learning outcomes**

The students have gained first experiences concerning the working methods of Theoretical Physics. They are familiar with the principles of theoretical mechanics and their different formulations. They are able to independently apply the acquired mathematical methods and techniques to simple problems of Theoretical Physics and to interpret the results. They have especially acquired knowledge of basic mathematical concepts.

**Courses**

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

V (4) + Ü (2)

Module taught in: Ü: German or English

**Method of assessment**

**Type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus**
written examination (approx. 120 minutes)
Language of assessment: German and/or English

**Allocation of places**

--

**Additional information**

Registration: If a student registers for the exercises 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: Quantum Mechanics  
Abbreviation: 11-T-Q-152-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: undergraduate  
Other prerequisites: Admission prerequisite to assessment: completion of exercises (approx. 13 exercise sheets per semester). Students who successfully completed approx. 50% of exercises will qualify for admission to assessment. The lecturer will inform students about the respective details at the beginning of the semester.

Contents:
1. History and basics: Limits of classical physics; fundamental historical experiments; from classical physics to quantum mechanics (QM);
2. Wave function and Schrödinger equation (SG): SG for free particles; superposition; probability distribution for pulse measurement; correspondence principles: postulates of QM; Ehrenfest theorem; continuity equation; stationary solutions of SG
3. Formalisation of QM: Eigenvalue equations; Physical significance of the eigenvalues of an operator; state space and Dirac notation; representations in state space; tensor products of state spaces;
4. Postulates of QM (and their interpretation): State; measurement; chronological development; energy-time uncertainty;
5. One-Dimensional problems: The harmonic oscillator; potential level; potential barrier; potential well; symmetry properties;
6. Spin-1/2 systems I: Theoretical description in Dirac notation; Spin 1/2 in the homogeneous magnetic field; two-level systems (qubits);
7. Angular momentum: Commutation and rotations; eigenvalues of the angular momentum operators (abstract); solution of the eigenvalue equation in polar coordinates (concrete);
8. Central potential - hydrogen atom: Bonding states in 3D; Coulomb potential;
9. Motion in an electromagnetic field: Hamiltonian; Normal Zeeman effect; canonical and kinetic momentum; Gauge transformation; Aharonov-Bohm effect; Schrödinger, Heisenberg and interaction representation; motion of a free electron in a magnetic field;
10. Spin-1/2 systems II: Formulation using angular momentum algebra;
11. Addition of angular momenta:
12. Approximation methods: Stationary perturbation theory (with examples); variational method; WKB method; time-dependent perturbation theory;
13. Atoms with several electrons: Identical particles; Helium atom; Hartree and Hartree-Fock approximation; atomic structure and Hund’s rules

Intended learning outcomes:
The students have gained first experiences concerning the working methods of Theoretical Physics. They are familiar with the principles of quantum theory. They are able to apply the acquired mathematical methods and techniques to simple problems of quantum theory and to interpret the results. They have especially acquired knowledge of advanced mathematical concepts.

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

Method of assessment:
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 120 minutes)
Language of assessment: German and/or English
### Allocation of places

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### Additional information

Registration: If a student registers for the exercises 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)

---
Subfield Statistical Physics and Electrodynamics

(16 ECTS credits)
Module title | Abbreviation
---|---
Statistical Physics and Electrodynamics | 11-T-SE-152-m01

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

Module offered by
Faculty of Physics and Astronomy

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

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

Contents

A. Statistical Physics;
o. Principles of statistics: Elements of statistics (central limit theorem and statistics of extremes); Micro- and macro-states; probability space (conditional probability, statistical independence);
1. Statistical Physics: Entropy and probability theory; entropy in classical physics; thermodynamic equilibrium in closed and open systems (with energy and / or particle exchange);
2. Ideal systems: Spin systems; linear oscillators; ideal gas;
3. Statistical Physics and thermodynamics: The 1st law; quasi-static processes; entropy and temperature; generalised forces; the second and third law; reversibility; transition from Statistical Physics to thermodynamics;
4. Thermodynamics: Thermodynamic fundamentals relationship; thermodynamic potentials; changes of state; thermodynamic machines (Carnot engine and efficiency); chemical potential;
5. Ideal Systems II, quantum statistics: Systems of identical particles; ideal Fermi gas; ideal Bose gas and Bose-Einstein condensation; grids and normal modes; Phonons;
6. Systems of interacting particles: Approximation methods (mean-field theory, Sommerfeld expansion); computer simulation (Monte Carlo method); interacting phonons (Debye approximation); Ising models (particularities in 1 and 2 dimensions); Yang-Lee-theorems; Van der Waals equation for real interacting gases;
7. Critical phenomena: Scaling laws, critical slowing down, fast variable as Bad (electron-phonon interaction and BCS superconductivity); magnetism (quantum criticality at low temperatures, quantum phase transitions at T = 0); problems of the thermodynamic limit;

B. Electrodynamics;
o. Mathematical tools: Gradient, divergence, curl; curve, surface, volume integrals; Stokes and Gaussian sentence; Delta function; Fourier transform; full functional systems; solving PDEs;
1. Maxwell equations;
2. Electrostatics: Coulomb’s law; electrostatic potential; charged interface; electrostatic field energy (capacitor); multipole expansion; Boundary value problems; numerical solution; Image charges; Green’s functions; development according to orthogonal functions;
3. Magnetostatics: Current density; continuity equation; vector potential; Biot-Savart law; magnetic moment; analogies to electrostatics;
4. Maxwell equations in matter: Electrical and magnetic susceptibility; interfaces;
5. Dynamics of electromagnetic fields: Faraday induction; RCL-circuits; field energy and pulse; potentials; plane waves; wave packets; plane waves in matter; cavity resonators and wave guides; inhomogeneous wave equation; temporally oscillating sources and dipole radiation; accelerated point charges;
6. Special Theory of Relativity: Lorentz transform; simultaneity; length contraction and time dilation; light cone; effect, energy and momentum; co- and contra-variant tensors; covariant classical mechanics;
7. Covariant electrodynamics: Field strength tensor and Maxwell’s equations; transformation of the fields; Doppler effect; Lorentz force

Intended learning outcomes
The students have advanced knowledge of the methods of Theoretical Physics. They know the principles of electrodynamics, thermodynamics and statistical mechanics. They are able to discuss the acquired theoretical concepts and to attribute them to bigger physical contexts.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + V (4)
<table>
<thead>
<tr>
<th>Method of assessment</th>
<th>(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)</th>
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<tbody>
<tr>
<td>Oral examination of one candidate each (approx. 30 minutes)</td>
<td>Language of assessment: German and/or English</td>
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| Allocation of places | --                                                                                                                                                                                                 |

| Additional information | --                                                                                                                                                                                                 |

| Referred to in LPO I | (examination regulations for teaching-degree programmes)                                                                                                                                              |
Module title | Abbreviation
--- | ---
Statistical Physics - Exercises | 11-T-SA-152-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)
--- | --- | ---
5 | numerical grade | --

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

Contents
Exercises in Statistical Physics and theoretical thermodynamics according to the content of 11 T-SEV content. Among others, principles of statistics, Statistical Physics, ideal systems, fundamental theorems, thermodynamic potentials, quantum statistics, Fermi and Bose gas, systems of interacting particles, approximation methods, Ising models, critical phenomena, etc.

Intended learning outcomes
The students are familiar with the mathematical methods of theoretical thermodynamics and Statistical Physics and are able to independently apply them to the description and solution of problems of Statistical Physics and to interpret the results in a physical manner.

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

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 120 minutes)
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

**Electrodynamics - Exercises**

### Abbreviation

11-T-EA-152-m01

### Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

### 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

Undergraduate

### Other prerequisites

--

### Contents

Exercises in electrodynamics according to the content of 11 T-SEV. Among others Mathematical tools, Maxwell's equations, electrostatics, magnetostatics, Maxwell equations in matter, dynamic electromagnetic fields, electromagnetic waves, special relativity, covariant electrodynamics etc.

### Intended learning outcomes

The students are familiar with the mathematical methods of theoretical electrodynamics and are able to independently apply them to the description and solution of problems of electrodynamics and to interpret the results in a physical manner.

### Courses

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<th>(type, number of weekly contact hours, language — if other than German)</th>
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<td>Ü (2)</td>
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</table>

Module taught in: Ü: German or English

### Method of assessment

- **written examination** (approx. 120 minutes)
  - Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

--
Subfield Laboratory Course Physics
(15 ECTS credits)
<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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</thead>
<tbody>
<tr>
<td>Laboratory Course Physics A(Mechanics, Heat, Electromagnetism)</td>
<td>11-P-PA-152-m01</td>
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<th>Module coordinator</th>
<th>Module offered by</th>
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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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<th>ECTS</th>
<th>Method of grading</th>
<th>Only after succ. compl. of module(s)</th>
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<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</tbody>
</table>

### Contents

Measurement tasks in mechanics, thermodynamics and electricity theory, e.g. measurement of voltages and currents, heat capacity, calorimetry, density of bodies, dynamic viscosity, elasticity, surface tension, spring constant, drafting of graphics and drafting of measurement protocols.

### Intended learning outcomes

The students know and have mastered physical measuring methods and experimenting techniques. They are able to independently plan and conduct experiments, to cooperate with others, and to document the results in a measuring protocol.

### Courses

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

P (2)

### Method of assessment

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

practical assignment with talk (approx. 30 minutes)

Preparing, performing and evaluating (record of readings or lab report) the experiments will be considered successfully completed if a Testat (exam) is passed. Exactly one experiment that was not successfully completed can be repeated once. After completion of all experiments, talk (with discussion; approx. 30 minutes) to test the candidate’s understanding of the physics-related contents of the module. Talks that were not successfully completed can be repeated once. Both components of the assessment have to be successfully completed.

### Allocation of places

--

### Additional information

--

### Referred to in LPO I

(examination regulations for teaching-degree programmes)

--
### Module title
Data and Error Analysis

### Abbreviation
11-P-FR1-152-m01

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

### Module offered by
Faculty of Physics and Astronomy

### ECTS
2

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

### Duration
1 semester

### Module level
undergraduate

### Other prerequisites
Admission prerequisite to assessment: completion of exercises (approx. 13 exercise sheets per semester). Students who successfully completed approx. 50% of exercises will qualify for admission to assessment. The lecturer will inform students about the respective details at the beginning of the semester.

### Contents
Types of errors, error approximation and propagation, graphic representations, linear regression, mean values and standard deviation.

### Intended learning outcomes
The students are able to evaluate measuring results on the basis of error propagation and of the principles of statistics and to draw, present and discuss the conclusions.

### Courses
V (1) + Ü (1)

Module taught in: Ü: German or English

### Method of assessment
written examination (approx. 120 minutes)

Language of assessment: German and/or English

### Allocation of places
--

### Additional information
Registration: If a student registers for the exercises 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)

§ 53 I Nr. 1 c)  
§ 77 I Nr. 1 d)
**Module title**  
Laboratory Course Physics B for Students of Mathematical Physics

**Abbreviation**  
11-P-MPB-152-m01

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

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

<table>
<thead>
<tr>
<th>ECTS</th>
<th>Method of grading</th>
<th>Only after succ. compl. of module(s)</th>
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<tbody>
<tr>
<td>4</td>
<td>(not) successfully completed</td>
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</table>

**Duration**  
undergraduate

**Other prerequisites**  
Students are highly recommended to complete modules 11-P-PA and 11-P-FR1 prior to completing module 11-P-MPB.

### Contents

Physical laws of optics, vibrations and waves, science of electricity and circuits with electric components.

### Intended learning outcomes

The students know and have mastered physical measuring methods and experimenting techniques. They are able to independently plan and conduct experiments, to cooperate with others, and to document the results in a measuring protocol. They are able to evaluate the measuring results on the basis of error propagation and of the principles of statistics and to draw, present and discuss the conclusions.

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

P (2)

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

practical assignment with talk (approx. 30 minutes)

Preparing, performing and evaluating (record of readings or lab report) the experiments will be considered successfully completed if a Testat (exam) is passed. Exactly one experiment that was not successfully completed can be repeated once. After completion of all experiments, talk (with discussion; approx. 30 minutes) to test the candidate's understanding of the physics-related contents of the module. Talks that were not successfully completed can be repeated once. Both components of the assessment have to be successfully completed.

**Allocation of places**

--

**Additional information**

--

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

--
# Module Catalogue for the Subject Mathematical Physics

## Bachelor's with 1 major, 180 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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</thead>
<tbody>
<tr>
<td>Laboratory Course Physics C for Students of Mathematical Physics</td>
<td>11-P-MPC-152-m01</td>
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<th>Module offered by</th>
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<td>Faculty of Physics and Astronomy</td>
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<th>Method of grading</th>
<th>Other prerequisites</th>
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<tbody>
<tr>
<td>4</td>
<td>Only after succ. compl. of module(s)</td>
<td>Students are highly recommended to complete module 11-P-MPB prior to completing module 11-P-MPC.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>undergraduate</td>
<td></td>
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</tbody>
</table>

## Contents

Physical laws of wave optics, Molecular, Atomic and Nuclear Physics and modern measuring methods using special computerised devices with examples from optics and Solid-State Physics.

## Intended learning outcomes

The students are able to build and almost independently operate advanced experimental setups. They are able to record measuring results in a structured manner, even in case of huge data traffic, and to analyse the results by using error propagation and statistics. They are able to evaluate results, to draw conclusions and to present and discuss them in a scientific paper and a presentation.

## Courses

| P (2) |

## Method of assessment

practical assignment with talk (approx. 30 minutes) Preparing, performing and evaluating (record of readings or lab report) the experiments will be considered successfully completed if a Testat (exam) is passed. Exactly one experiment that was not successfully completed can be repeated once. After completion of all experiments, talk (with discussion; approx. 30 minutes) to test the candidate's understanding of the physics-related contents of the module. Talks that were not successfully completed can be repeated once. Both components of the assessment have to be successfully completed.

## Allocation of places

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## Additional information

--

## Referred to in LPO I

(examination regulations for teaching-degree programmes)

--
Module title | Abbreviation
---|---
Advanced and Computational Data Analysis | 11-P-FR2-152-m01

Module coordinator
Managing Director of the Institute of Applied Physics

Module offered by
Faculty of Physics and Astronomy

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
2 | (not) successfully completed |

Duration | Module level | Other prerequisites
---|---|---
1 semester | undergraduate | Students are highly recommended to complete module 11-P-FR1 prior to completing module 11-P-FR2.

Contents
Advanced methods of data analysis and error calculation. Distribution function, significance tests, modelling. Computerised data analysis.

Intended learning outcomes
The students have advanced knowledge of the analysis of measuring data and error calculation. They have mastered methods of computerised data analysis are able to apply them to self-obtained measuring data and to discuss the results.

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

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
Exercises (successful completion of approx. 50% of approx. 10 exercise sheets)
Assessment offered: Once a year, summer semester

Allocation of places
--

Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Compulsory Electives Analysis and Linear Algebra
(10 ECTS credits)
Subgroup Basics of Mathematical Methods
(5 ECTS credits)
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<td>Analysis 1 for Mathematical Physics</td>
<td>10-M-ANAP1:202-m01</td>
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**Contents**

Real numbers and completeness; complex numbers; basic topological notions; convergence and divergence of sequences and series; power series and Taylor series; basics in differential calculus in one variable; basics of integral calculus in one variable (Riemann integral and improper integral).

**Intended learning outcomes**

The student knows and masters the essential methods and notions of analysis. He/She is acquainted with the central proof methods in analysis and can employ them to solve easy problems. He/she is able to perform easy mathematical arguments independently and to express mathematical arguments precisely and clearly in written form.

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

Ü (2)

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

written examination (approx. 90 to 180 minutes) and
written exercises (approx. 12 exercise sheets with approx. 4 exercises each)

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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<tr>
<td>Analysis 2 for Mathematical Physics</td>
<td>10-M-ANAP2-202-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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**Contents**
Further topological considerations, normed and metric spaces; basics in differential calculus in several variables, Taylor’s theorem for multivariate functions, Banach fixed point theorem, inverse function theorem, implicit function theorem

**Intended learning outcomes**
The student knows and masters the essential methods and notions of analysis. He/She is acquainted with the central proof methods in analysis and can employ them to solve easy problems. He/she is able to perform easy mathematical arguments independently and to express mathematical arguments precisely and clearly in written form.

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

| Ü (2) |

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

- written examination (approx. 90 to 180 minutes) and
- written exercises (approx. 12 exercise sheets with approx. 4 exercises each)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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

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Subfield Lineare Algebra

(5 ECTS credits)
<table>
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<tbody>
<tr>
<td>Linear Algebra 1 for Mathematical Physics</td>
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</table>

**Contents**

Basic notions and structures: groups, rings, fields, polynomials; matrices: Gauß algorithm, echelon form, rank; vector spaces over arbitrary fields: linear independance, basis, dimension, coordinates, change of basis, sums, direct sums and quotients of subspaces, linear maps, kernel and image, dimension theorem, matrix representation, determinants.

**Intended learning outcomes**

The student knows and masters the basic notions and essential methods of linear algebra. He/She is acquainted with the central proof methods in linear algebra and can apply them to solve easy problems. He/She is able to perform simple mathematical arguments independently, and can present them adequately in written form.

**Courses**

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

Ü (2)

**Method of assessment**

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

written examination (approx. 90 to 180 minutes) and written exercises (approx. 12 exercise sheets with approx. 4 exercises each)

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

**Lineare Algebra 2 for Mathematical Physics**

| Abbreviation | 10-M-LNAP2-202-m01 |

### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

### ECTS

5

### Method of grading

Only after succ. compl. of module(s)

### Duration

1 semester

### Module level

undergraduate

### Other prerequisites

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### Contents

Eigenvalue theory: characteristic polynomial, Caley-Hamilton theorem, minimal polynomial, invariant subspaces, diagonalisability, nilpotent maps, Jordan normal form; Euclidean/unitary spaces: scalar product, orthonormal bases, orthogonal complement, orthogonal/unitary matrices, selfadjoint and normal matrices, positive definite matrices.

### Intended learning outcomes

The student knows and masters the basic notions and essential methods of linear algebra. He/She is acquainted with the central proof methods in linear algebra and can apply them to solve easy problems. He/She is able to perform simple mathematical arguments independently, and can present them adequately in written form.

### Courses

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

**Ü (2)**

### Method of assessment

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

written examination (approx. 90 to 180 minutes) and written exercises (approx. 12 exercise sheets with approx. 4 exercises each)

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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Mathematical Methods
(18 ECTS credits)
Subgroup Basics of Mathematical Methods

(5 ECTS credits)
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<td>Introduction to Differential Geometry</td>
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**Contents**

Curves in $\mathbb{R}^n$ and $\mathbb{R}^3$: Frenet equations, Frenet–Serret frame, curvature and torsion of curves; 2-dimensional surfaces in $\mathbb{R}^3$: parametrisation of surfaces, examples; fundamental forms (metrics, normal vector fields); area of surfaces; curvature; outlook to further topics in differential geometry, for example covariant derivatives, minimal surfaces, submanifolds.

**Intended learning outcomes**

The student knows and masters the essential methods and basic notions in differential geometry. He/She is acquainted with the central concepts in this field, and is able to apply the fundamental proof methods independently.

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

V (4) + Ü (2)

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

a) written examination (approx. 90 to 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)
credible for bonus

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

**Allocation of places**

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**Additional information**

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

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Module title: Ordinary Differential Equations  
Abbreviation: 10-M-DGL-202-m01

Module coordinator:  
Dean of Studies Mathematik (Mathematics)

Module offered by:  
Institute of Mathematics

ECTS: 5  
Method of grading: Only after succ. compl. of module(s)  
(5) successfully completed

Duration: 1 semester  
Module level: undergraduate

Other prerequisites: --

Contents:
Notion of a solution, simple solution methods for scalar differential equations (separation of variables, variation of constants, exact equations) and particular examples like Bernoulli, Riccati; initial value problem; existence and uniqueness of solutions; Gronwall lemma; extendability of solutions, maximal solution; continuous dependence of solutions on initial values, linear differential equations, algebraic structure of solution spaces, solution methods, matrix exponential function; autonomous systems; notion of stability; stability of linear systems; linearized asymptotic stability; Lyapunov methods, first integrals.

Intended learning outcomes:
The student is acquainted with the fundamental concepts and methods of the theory of ordinary differential equations. He/she is able to apply these methods to practical problems.

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 is creditable for 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)
creditable for bonus
Language of assessment: German and/or English

Allocation of places:
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Additional information:
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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<td>Introduction to Complex Analysis</td>
<td>10-M-FTH-202-m01</td>
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**Contents**

Complex differentiability, Cauchy-Riemann differential equations, conformal maps (in particular Möbius transformations), complex integration, Cauchy's integral theorem and Cauchy's integral formula, basic principles of complex analysis (in particular identity theorem, maximum principle, openness principle, Schwarz lemma), general Cauchy integral theorem, isolated singularities and Laurent series, residue theorem and its applications (computation of real integrals, argument principle, Rouche's theorem), normal families (in particular Montel's theorem and Vitali's theorem), Riemann's mapping theorem.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods in complex analysis. He/she is able to apply these methods to practical problems.

**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 is creditable for 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)
creditable for bonus

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
Geometric Analysis

### Abbreviation
10-M-GAN-202-m01

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### Contents
Submanifolds of $\mathbb{R}^n$ and regular value theorem; submanifolds with and without boundary; orientation; differential forms and exterior derivative; Stokes' theorem for differential forms; Hodge star operator; Stokes' theorem and its special cases Gauss' theorem and Green's theorem; outlook on further topics like density or submanifolds with corners.

### Intended learning outcomes
The student is acquainted with the fundamental concepts and methods in geometric analysis. He/she is able to apply these methods to practical problems.

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

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

- 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)

creditable for bonus

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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### Contents
Banach spaces; function spaces (L^p spaces of continuous functions, Sobolev spaces), denseness, separability; linear operators, fundamental theorems for linear operators; Baire's theorem, uniform boundedness principle, open mapping theorem, closed graph theorem; linear functionals and dual spaces; Hahn-Banach theorem (extension theorem, separation theorem), double dual space and reflexivity; weak convergence, Banach-Alaoglu theorem, adjoint operator, closed range theorem; Hilbert spaces: Fréchet-Riesz representation theorem, orthonormal systems; compact sets and operators, Arzela-Ascoli theorem; spectral theory: basic notions, spectral theory of compact normal and self-adjoint operators in Hilbert spaces.

### Intended learning outcomes
The student knows the fundamental concepts and methods of functional analysis as well as the pertinent proof methods, is able to apply methods from linear algebra and analysis to functional analysis, and realises the broad applicability of the theory to other branches of mathematics.

### 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 is creditable for 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) creditable for bonus

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 Partial Differential Equations

### Abbreviation
10-M-PAR-202-m01

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

### Module offered by
Institute of Mathematics

### ECTS
5

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

### Duration
1 semester

### Module level
undergraduate

### Other prerequisites
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### Contents
Examples of partial differential equations; existence and uniqueness theorems; exact solutions for the linear transport equation, the Poisson equation, the heat equation and the wave equation; boundary value problems, Dirichlet problems; energy methods, Green’s functions, maximum principle; explicit solutions for general nonlinear partial differential equations of first order; Hopf-Lax formula for Hamilton-Jacobi equations; Lax-Oleinik formula for scalar conservation laws; further methods for solving partial differential equations (e.g., separation of variables, Fourier and Laplace transformation).

### Intended learning outcomes
The student is acquainted with the fundamental concepts and methods in the theory of partial differential equations. He/she is able to apply these methods to practical problems.

### 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 is creditable for 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) creditable for bonus

Language of assessment: German and/or English

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

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

(13 ECTS credits)
### Module title
Overview Differential Geometry and Ordinary Differential Equations for Mathematical Physics

### Abbreviation
10-M-DGGD-PÜ-152-m01

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

### Module offered by
Institute of Mathematics

### ECTS
13

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

### Numerical grade
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### Duration
1 semester

### Module level
undergraduate

### Other prerequisites
--

### Contents
Curves in Euclidean spaces, curvature, Frenet equations, local classification, submanifolds (hypersurfaces in particular) in Euclidean spaces, curvature of hypersurfaces, geodesics, isometries, main theorem on local surface theory, special classes of surfaces; existence and uniqueness theorem, continuous dependence of solutions on initial values, systems of linear differential equations, matrix exponential series, linear differential equations of higher order.

### Intended learning outcomes
The student is acquainted with fundamental concepts and methods in differential geometry and the theory of ordinary differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

### 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 is creditable for bonus)
oral examination of one candidate each (20 to 40 minutes)
Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).
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
Overview Complex Analysis and Differential Geometry for Mathematical Physics

### Abbreviation
10-M-FTDG-PÜ-152-m01

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

### Module offered by
Institute of Mathematics

### ECTS
13

### 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
Complex differentiability and Cauchy-Riemann differential equations, path integrals and Cauchy integral theorems, isolated singularities, meromorphic functions and Laurent series, residue theorem and applications, Weierstrass product theorem and theorem of Mittag-Leffler, conformal maps; curves in Euclidean spaces, curvature, Frenet equations, local classification, submanifolds (hypersurfaces in particular) in Euclidean spaces, curvature of hypersurfaces, geodesics, isometries, main theorem on local surface theory, special classes of surfaces.

### Intended learning outcomes
The student is acquainted with fundamental concepts and methods in complex analysis and differential geometry. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

### Courses
V (4) + Ü (2)

### Method of assessment
oral examination of one candidate each (20 to 40 minutes)

Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

Language of assessment: German and/or English

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

Complex differentiability and Cauchy-Riemann differential equations, path integrals and Cauchy integral theorems, isolated singularities, meromorphic functions and Laurent series, residue theorem and applications, Weierstraß product theorem and theorem of Mittag-Leffler, conformal maps; existence and uniqueness theorem, continuous dependence of solutions on initial values, systems of linear differential equations, matrix exponential series, linear differential equations of higher order.

## Intended learning outcomes

The student is acquainted with fundamental concepts and methods in complex analysis and the theory of ordinary differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

## 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 is creditable for bonus)

oral examination of one candidate each (20 to 40 minutes)

Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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
Mathematical Physics
Bachelor's with 1 major, 180 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview Geometric Analysis and Differential Geometry for Mathematical Physics</td>
<td>10-M-GADG-PÜ-152-m01</td>
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<table>
<thead>
<tr>
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<td>Institute of Mathematics</td>
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<thead>
<tr>
<th>ECTS</th>
<th>Method of grading</th>
<th>Other prerequisites</th>
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<tbody>
<tr>
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<table>
<thead>
<tr>
<th>Duration</th>
<th>Module level</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</table>

**Contents**

Fundamentals in analysis on manifolds, submanifolds, calculus of differential forms, Stoke's theorem and applications in vector analysis and topology; curves in Euclidean spaces, curvature, Frenet equations, local classification, submanifolds (hypersurfaces in particular) in Euclidean spaces, curvature of hypersurfaces, geodesics, isometries, main theorem on local surface theory, special classes of surfaces.

**Intended learning outcomes**

The student is acquainted with fundamental concepts and methods in geometric analysis and differential geometry. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

**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 is creditable for bonus)

oral examination of one candidate each (20 to 40 minutes)

Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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>
<tr>
<td>Intended learning outcomes</td>
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</tr>
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<td>Courses (type, number of weekly contact hours, language — if other than German)</td>
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<tr>
<td>Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)</td>
<td>oral examination of one candidate each (20 to 40 minutes)</td>
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<td>Additional information</td>
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
13

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

### Numerical grade
--

### Duration
1 semester

### Module level
undergraduate

### Other prerequisites
--

### Contents
Fundamentals in analysis on manifolds, submanifolds, calculus of differential forms, Stoke's theorem and applications in vector analysis and topology; complex differentiability and Cauchy-Riemann differential equations, path integrals and Cauchy integral theorems, isolated singularities, meromorphic functions and Laurent series, residue theorem and applications, Weierstraß product theorem and theorem of Mittag-Leffler, conformal maps.

### Intended learning outcomes
The student is acquainted with fundamental concepts and methods in geometric analysis and complex analysis. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

### Courses
(V (4) + Ü (2))

### Method of assessment
oral examination of one candidate each (20 to 40 minutes)
Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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

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

Banach spaces and Hilbert spaces, bounded operators, principles of functional analysis; existence and uniqueness theorem, continuous dependence of solutions on initial values, systems of linear differential equations, matrix exponential series, linear differential equations of higher order.

**Intended learning outcomes**

The student is acquainted with fundamental concepts and methods in functional analysis and the theory of ordinary differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

**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 is creditable for bonus)

oral examination of one candidate each (20 to 40 minutes)
Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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 Mathematical Physics

**Bachelor’s with 1 major, 180 ECTS credits**

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### Intended learning outcomes

The student is acquainted with fundamental concepts and methods in functional analysis and complex analysis. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

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### Method of assessment

Oral examination of one candidate each (20 to 40 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 title | Abbreviation
--- | ---
Overview Functional Analysis and Geometric Analysis for Mathematical Physics | 10-M-FAGA-PÜ-152-m01

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

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

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

**Contents**
Banach spaces and Hilbert spaces, bounded operators, principles of functional analysis; fundamentals in analysis on manifolds, submanifolds, calculus of differential forms, Stokes's theorem and applications in vector analysis and topology.

**Intended learning outcomes**
The student is acquainted with fundamental concepts and methods in functional analysis and geometric analysis. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

**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 is creditable for 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
Overview Differential Geometry and Partial Differential Equations for Mathematical Physics

Abbreviation
10-M-DGPA-PÜ-152-m01

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

ECTS
13

Method of grading
numerical grade

Duration
1 semester

Module level
undergraduate

Other prerequisites
--

Contents
Curves in Euclidean spaces, curvature, Frenet equations, local classification, submanifolds (hypersurfaces in particular) in Euclidean spaces, curvature of hypersurfaces, geodesics, isometries, main theorem on local surface theory, special classes of surfaces; examples of partial differential equations and partial differential equations of first order, existence and uniqueness theorems, basic equations of mathematical physics, boundary value problems, maximum principle and Dirichlet problem.

Intended learning outcomes
The student is acquainted with fundamental concepts and methods in differential geometry and the theory of partial differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

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

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Additional information
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**Module offered by**
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**Duration**
1 semester

**Module level**
undergraduate

**Other prerequisites**
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**Contents**
Existence and uniqueness theorem, continuous dependence of solutions on initial values, systems of linear differential equations, matrix exponential series, linear differential equations of higher order; examples of partial differential equations and partial differential equations of first order, existence and uniqueness theorems, basic equations of mathematical physics, boundary value problems, maximum principle and Dirichlet problem.

**Intended learning outcomes**
The student is acquainted with fundamental concepts and methods in the theory of ordinary and partial differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

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

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

Oral examination of one candidate each (20 to 40 minutes)
Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).
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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## Module Catalogue for the Subject
### Mathematical Physics

#### Bachelor’s with 1 major, 180 ECTS credits

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### Intended learning outcomes

The student is acquainted with fundamental concepts and methods in complex analysis and the theory of partial differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

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  - Language of assessment: German and/or English

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### Overview Geometric Analysis and Partial Differential Equations for Mathematical Physics

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### Contents
Basics in analysis on manifolds, e.g. submanifolds and calculus of differential forms, Stoke's theorem and its applications in vector calculus and topology, examples of first order partial differential equations, existence and uniqueness theorems, basic equations in mathematical physics, boundary value theorems, maximum principle and Dirichlet problem.

### Intended learning outcomes
The student is acquainted with fundamental concepts and methods in geometric analysis and the theory of partial differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

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Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
( examination regulations for teaching-degree programmes)
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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Overview Functional Analysis and Partial Differential Equations for Mathematical Physics</td>
<td>10-M-FAPA-PÜ-152-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

**ECTS** 13

**Method of grading**
numerical grade

**Duration** 1 semester

**Module level** undergraduate

**Other prerequisites**
--

**Contents**
Banach spaces and Hilbert spaces, bounded operators, principles of functional analysis; examples of partial differential equations and partial differential equations of first order, existence and uniqueness theorems, basic equations of mathematical physics, boundary value problems, maximum principle and Dirichlet problem.

**Intended learning outcomes**
The student is acquainted with fundamental concepts and methods in functional analysis and the theory of partial differential equations. He/She is able to relate these concepts with one another, and realises the advantages of thinking across the borders of different branches in mathematics.

**Courses**
V (4) + Ü (2)

**Method of assessment**
oral examination of one candidate each (20 to 40 minutes)
Assessment will have reference to two topics in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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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Mathematical Physics
(18 ECTS credits)
Module Group Supplementary Topics in Mathematics
(ECTS credits)
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<tbody>
<tr>
<td>Numerical Mathematics 1 for Mathematical Physics</td>
<td>10-M-NUM1P-152-m01</td>
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</table>

**Contents**

Solution of systems of linear equations and curve fitting problems, nonlinear equations and systems of equations, interpolation with polynomials, splines and trigonometric functions, numerical integration.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods in numerical mathematics, applies them to practical problems and knows about their typical fields of application.

**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 is creditable for 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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<td>Numerical Mathematics 2 for Mathematical Physics</td>
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</table>

**Contents**

Eigenvalue problems, linear programming, methods for initial value problems for ordinary differential equations, boundary value problems.

**Intended learning outcomes**

The student is able to draw a distinction between the different concepts of numerical mathematics and knows about their advantages and limitations concerning the possibilities of application in different fields of natural and engineering sciences and economics.

**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 is creditable for 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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<td>Stochastics 1 for Mathematical Physics</td>
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</table>

**Contents**

Combinatorics, Laplace models, selected discrete distributions, elementary measure and integration theory, continuous distributions: normal distribution, random variable, distribution function, product measures and stochastic independence, elementary conditional probability, characteristics of distributions: expected value and variance, limit theorems: law of large numbers, central limit theorem.

**Intended learning outcomes**

The student is acquainted with fundamental concepts and methods in stochastics, applies these methods to practical problems and knows about the typical fields of application.

**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 is creditable for 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**

--

**Additional information**

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

--
## Module title

Stochastics 2 for Mathematical Physics

| Abbreviation | 10-M-STO2P-152-m01 |

## Module coordinator

Dean of Studies Mathematik (Mathematics)

## Module offered by

Institute of Mathematics

## ECTS

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## Duration

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## Contents

Elements of data analysis, statistics of data in normal and other distributions, elements of multivariate statistics.

## Intended learning outcomes

The student is acquainted with fundamental concepts and methods in statistics, applies these methods to practical problems and knows about the typical fields of application.

## Courses

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## Method of assessment

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Language of assessment: German and/or English

Creditable for bonus

## Allocation of places

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## Additional information

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<td>Introduction to Algebra for Mathematical Physics</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

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**Duration**
1 semester

**Module level**
undergraduate

**Other prerequisites**
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**Contents**
Fundamental algebraic structures (groups, rings, fields), Galois theory.

**Intended learning outcomes**
The student knows and masters the essential methods and basic notions in algebra. He/She is acquainted with the central concepts in this field, and is able to apply the fundamental proof methods independently.

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

V (4) + Ü (2)

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

a) written examination (approx. 90 to 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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<td>Introduction to Discrete Mathematics for Mathematical Physics</td>
<td>10-M-DIMP-152-m01</td>
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</table>

**Contents**

Techniques from combinatorics, introduction to graph theory (including applications), cryptographic methods, error-correcting codes.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and results in discrete mathematics, masters the relevant proof techniques, is able to apply methods from number theory and algebra to discrete mathematics and realises the scope of applications of discrete structures.

**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 is creditable for 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

**Allocation of places**

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**Additional information**

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<td>Introduction to Projective Geometry for Mathematical Physics</td>
<td>10-M-PGEP-152-m01</td>
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</table>

**Contents**

Projective and affine planes, projective and affine spaces, theorem of Desargues, fundamental theorems for projective spaces, dualities and polarities of projective spaces.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods of projective geometry. He/she is able to apply these methods to practical problems.

**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 is creditable for 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 Catalogue for the Subject Mathematical Physics

**Bachelor's with 1 major, 180 ECTS credits**

<table>
<thead>
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<td>Introduction to Number Theory for Mathematical Physics</td>
<td>10-M-ZTHP-152-m01</td>
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#### Contents

Elementary properties of divisibility, prime numbers and prime number factorisation, modular arithmetics, prime tests and methods for factorisation, structure of the residue class rings, theory of quadratic remainder, quadratic forms, diophantine approximation and diophantine equations.

#### Intended learning outcomes

The student is acquainted with the fundamental concepts and methods of number theory. He/she is able to employ the basic methods and proof techniques independently.

#### 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 is creditable for 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
Operations Research for Mathematical Physics

### Abbreviation
10-M-ORSP-152-m01

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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 is creditable for 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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Bachelor's with 1 major Mathematical Physics

IMU Würzburg • generated 19-Jul-2022 • exam. data record Bachelor (180 ECTS) Mathematische Physik - 2020

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<tr>
<th><strong>Module title</strong></th>
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<tr>
<td>Introduction to Differential Geometry for Mathematical Physics</td>
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### Contents
Curves in Euclidean spaces, curvature, Frenet equations, local classification, submanifolds (hypersurfaces in particular) in Euclidean spaces, curvature of hypersurfaces, geodesics, isometries, main theorem on local surface theory, special classes of surfaces.

### Intended learning outcomes
The student knows and masters the essential methods and basic notions in differential geometry. He/She is acquainted with the central concepts in this field, and is able to apply the fundamental proof methods independently.

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

V (4) + Ü (2)

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

a) oral examination of one candidate each (15 to 30 minutes) or b) oral examination in groups of 2 candidates (10 to 15 minutes each)

Assessment will have reference to a topic in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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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<td>Ordinary Differential Equations for Mathematical Physics</td>
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**Contents**

Existence and uniqueness theorem; continuous dependence of solutions on initial values, systems of linear differential equations, matrix exponential series, linear differential equations of higher order.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods of the theory of ordinary differential equations. He/she is able to apply these methods to practical problems.

**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 is creditable for bonus)

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Assessment will have reference to a topic in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Introduction to Complex Analysis for Mathematical Physics</td>
<td>10-M-FTHP-152-m01</td>
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<table>
<thead>
<tr>
<th>Module coordinator</th>
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<tr>
<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<tr>
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<tbody>
<tr>
<td>1 semester</td>
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</table>

**Contents**


**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods in complex analysis. He/she is able to apply these methods to practical problems.

**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 is creditable for bonus)

a) oral examination of one candidate each (15 to 30 minutes) or b) oral examination in groups of 2 candidates (10 to 15 minutes each)

Assessment will have reference to a topic in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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(examination regulations for teaching-degree programmes)

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<td>Geometric Analysis for Mathematical Physics</td>
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</table>

**Contents**

Fundamentals in analysis on manifolds, submanifolds, calculus of differential forms, Stoke's theorem and applications in vector analysis and topology.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods in geometric analysis. He/she is able to apply these methods to practical problems.

**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 is creditable for bonus)

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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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<table>
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<tr>
<td>Introduction to Functional Analysis for Mathematical Physics</td>
<td>10-M-FANP-152-m01</td>
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</table>

**Contents**

Banach spaces and Hilbert spaces, bounded operators, principles of functional analysis.

**Intended learning outcomes**

The student knows the fundamental concepts and methods of functional analysis as well as the pertinent proof methods, is able to apply methods from linear algebra and analysis to functional analysis, and realises the broad applicability of the theory to other branches of mathematics.

**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 is creditable for bonus)

a) oral examination of one candidate each (15 to 30 minutes) or b) oral examination in groups of 2 candidates (10 to 15 minutes each)

Assessment will have reference to a topic in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).

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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<table>
<thead>
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<td>Introduction to Partial Differential Equations for Mathematical Physics</td>
<td>10-M-PARP-152-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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</table>

**Duration**
1 semester

**Module level**
undergraduate

**Other prerequisites**
--

**Contents**
Examples of partial differential equations and partial differential equations of first order, existence and uniqueness theorems, basic equations of mathematical physics, boundary value problems, maximum principle and Dirichlet problem.

**Intended learning outcomes**
The student is acquainted with the fundamental concepts and methods in the theory of partial differential equations. He/she is able to apply these methods to practical problems.

**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 is creditable for bonus)
a) oral examination of one candidate each (15 to 30 minutes) or b) oral examination in groups of 2 candidates (10 to 15 minutes each)
Assessment will have reference to a topic in pure mathematics as agreed upon with the examiner. Each topic may only be selected as the subject of one examination in the sub-field Gesamtüberblick Mathematische Methoden (Overview Mathematical Methods) or in module group Ergänzung Mathematik (Supplementary Topics in Mathematics).
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)
--
## Module title
Modeling and Computational Science

### Abbreviation
10-M-MWR-152-m01

## Module coordinator
Dean of Studies Mathematik (Mathematics)

## Module offered by
Institute of Mathematics

## ECTS
8

## Method of grading
numerical grade

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

## Duration
1 semester

## Module level
undergraduate

## Other prerequisites
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## Contents

## Intended learning outcomes
The student masters the fundamental mathematical methods and techniques to simulate processes from natural and engineering sciences on a computer.

## Courses

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

## Method of assessment

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<th>Information on whether module is creditable for bonus</th>
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<td>If not every semester, information on whether module is creditable for bonus</td>
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<td>b) oral examination of one candidate each</td>
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<tr>
<td>c) oral examination in groups</td>
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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)
--
Module Group Experimental Physics
(ECTS credits)
Module Catalogue for the Subject Mathematical Physics
Bachelor's with 1 major, 180 ECTS credits

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<td>Optics and Waves</td>
<td>11-E-O-152-m01</td>
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<td>Faculty of Physics and Astronomy</td>
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<td>undergraduate</td>
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</table>

Contents

1. Light (linked to 11-E-E): basic concepts, the speed of light, Huygens-Fresnel principle: reflection, refraction.
2. Light in matter: propagation velocity in the medium; dispersion, complex and frequency-dependent dielectric constant; absorption, Kramers-Kronig relation, interfaces, Fresnel equations, polarization, generation by absorption, birefringence, optical activity (dipole).
3. Geometrical optics: basic concepts, Fermat's principle, optical path, planar interfaces, Snell's law, total reflection, optical tunneling, evanescent waves, prism; normal and anomalous dispersion, curved interfaces, thin and thick lenses, lens systems, lens grinder formula, aberrations, imaging errors (spherical & chromatic aberration, astigmatism, coma, distortion, correction approaches).
4. Optical instruments: characteristics; camera, eye, magnifying glass, microscope, telescope types, bundle beam vs. image construction (electron lenses, electron microscope), confocal microscopy.
5. Wave optics: spatial and temporal coherence, Young's double slit experiment, interference pattern (intensity profile), thin films, parallel layers, wedge-shaped layers, phase shift, Newton rings, interferometer (Michelson, Mach-Zender, Fabry-Perot).
6. Diffraction in the far field: Fraunhofer diffraction, single slit, intensity distribution, apertures, resolving power, Rayleigh & Abbé criterion, Fourier optics, optical grating, n-fold slit, intensity distribution, grating spectrometer and resolution, diffraction off atomic lattices, convolution theorem.
7. Diffraction in the near field: Fresnel, near-field diffraction at circular apertures/disks, Fresnel zone plate, near-field microscopy, holography, Huygens-Fresnel concept; white light hologram.
8. Failure of classical physics I - from light wave to photon: black body radiation and Planck's quantum hypothesis; photoelectric effect and Einstein's explanation, Compton effect, light as a particle, wave-particle duality, quantum structure of nature.
9. Failure of classical physics II - particles as waves: de Broglie's matter wave concept; diffraction of particle waves (Davison-Germer-experiment, double slit interference).
10. Wave mechanics: wave packets, phase and group velocity (recap of 11-EM), uncertainty principle, Nyquist-Shannon theorem, wave function as probability amplitude, probability of residence, measurement process in quantum mechanics (double-slit experiment & which-way information, collapse of the wave function, Schrödinger's cat).
11. Mathematical concepts of quantum mechanics: Schrödinger equation as wave equation, conceptual comparison to wave optics, free particle and particles in a potential, time-independent Schrödinger equation as eigenvalue equation, simple examples in 1D (potential step, potential barrier and tunnel effect, box potential and energy quantization, harmonic oscillator), box potential in higher dimensions and degeneracy, formal theory of QM (states, operators, observables).

Intended learning outcomes

The students understand the basic principles and contexts of radiation, wave and quantum optics. They understand the theoretical concepts and know the structure and application of important optical instruments and measuring methods. They are able to apply mathematical methods to the formulation of physical contexts and autonomously apply their knowledge to the solution of mathematical-physical tasks.

Courses

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

V (4) + Ü (2)

Module taught in: Ü: German or English
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<th><strong>Method of assessment</strong> (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)</th>
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| written examination (approx. 120 minutes)  
Language of assessment: German and/or English |

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</table>
Module title | Abbreviation
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Atoms and Quanta | 11-E-A-152-m01

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

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

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

Contents

1. Structure of atoms: Experimental evidence for the existence of atoms, size of the atom, charges and masses in the atom, isotopes, internal structure, Rutherford experiment, instability of the "classical" Rutherford atom.
5. Fine and hyperfine structure: Electron spin and magnetic spin moment, Stern-Gerlach experiment, Einstein-de Haas effect, glimpse of the Dirac equation (spin as a relativistic phenomenon and existence of antimatter), electron spin resonance (ESR), spin-orbit interaction, relativistic fine structure, Lamb shift (quantum electrodynamics), nuclear spin and hyperfine structure.
7. Light-matter interaction: Time-dependent perturbation theory (Fermi's Golden Rule) and optical transitions, matrix elements and dipole approximation, selection rules and symmetry, line broadening (lifespan, Doppler effect, collision broadening), atomic spectroscopy.
8. Laser: Elementary optical processes (absorption, spontaneous and stimulated emission), stimulated emission as light amplification, Einstein's rate equations, thermal equilibrium, non-equilibrium character of a laser: Rate equations, population inversion and laser condition, basic structure of a laser, optical pumping, 2-, 3- and 4-level lasers, examples (ruby laser, He-Ne laser, semiconductor laser).
10. Molecules and chemical bonding: Molecular hydrogen ion (H\textsuperscript{2+}) as simplest example: Rigid molecule approximation and LCAO approach, bonding and anti-bonding molecular orbitals, hydrogen molecule (H\textsubscript{2}): Molecular orbital vs. Heitler-London approximation, diatomic heteronuclear molecules: covalent vs. ionic bonding, van der Waals bonds and Lennard-Jones potential, (time allowing: conjugated molecules).
11. Molecular rotations and vibrations: Born-Oppenheimer approximation, energy levels of the rigid rotator (symmetric and asymmetrical molecules), centrifugal expansion, molecule as (an)harmonic oscillator, Morse potential, normal modes, vibrational-rotational interaction.

Intended learning outcomes

The students understand the basic principles and contexts of quantum phenomena as well as Atomic and Molecular Physics. They understand the ideas and concepts of quantum theory and Astrophysics and the relevant experiments to observe and measure quantum phenomena. They are able to apply mathematical methods to the...
formulation of physical contexts and autonomously apply their knowledge to the solution of mathematical-physical tasks.

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<tr>
<td>Introduction to Solid State Physics</td>
<td>11-E-F-152-m01</td>
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**Contents**

1. The free-electron gas (FEG), free electrons; density of states; Pauli principle; Fermi-Dirac statistics; spec. heat, Sommerfeld coefficient; electrons in fields: Drude-Lorentz-Sommerfeld; electrical and thermal conductivity, Wiedemann-Franz law; Hall effect; limitations of the model
2. Crystal structure, periodic lattice; types of lattices; Bravais lattice; Miller indices; simple crystal structures; lattice defects; polycrystals; amorphous solids; group theoretical approaches, the importance of symmetry for electronic properties
3. The reciprocal lattice (RG), motivation: Diffraction; Bragg condition; definition; Brillouin zones; diffraction theory: Scattering; Ewald construction; Bragg equation; Laue’s equation; structure and form factor
4. Structure determination, probes: X-ray, electron, neutron; methods: Laue, Debye-Scherrer, rotating crystal; electron diffraction, LEED
5. Lattice vibrations (phonons), equations of motion; dispersion; group velocity; diatomic base: optical, acoustic branch; quantisation: Phonon momentum; optical properties in the infrared; dielectric function (Lorentz model); examples of dispersion curves (occ. Kramers-Kronig), measurement methods
6. Thermal properties of insulators, Einstein and Debye model; phonon density of states; anharmonicity and thermal expansion; thermal conductivity; Umklapp processes; crystal defects
7. Electrons in a periodic potential, Bloch theorem; band structure; approximation of nearly free electrons (NFE); strongly bound electrons (tight binding, LCAO); examples of band structures, Fermi surfaces, spin-orbit interaction
8. Superconductivity, BCS theory, pairing, coupling of bosonic and fermionic modes, band structure, many-particle aspects (quasiparticle concept)

**Intended learning outcomes**

The students understand the basic contexts and principles of Solid-State Physics (bonding and structure, lattice dynamics, thermal properties, principles of electronic properties (free electron gas)). They understand the structure of solids and know the experimental methods and theoretical models for the description of phenomena of Solid-State Physics. They are able to apply mathematical methods to the formulation of physical contexts and autonomously apply their knowledge to the solution of mathematical-physical tasks.

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

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

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

written examination (approx. 120 minutes)
Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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

--
Module title | Abbreviation
---|---
Nuclear and Elementary Particle Physics | 11-E-T-152-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 | undergraduate | --

Contents
1. Overview, historical introduction, history and significance of Nuclear and Particle Physics
2. Methods of Nuclear Physics, scattering and spectroscopy, nuclear radius, composition of matter, mass and charge distribution in the nucleus, the discovery of the proton and neutron
3. Nuclear models, the mass of the atomic nuclei, droplet model, bonding energy, nuclear shell model
4. Structure of cores, angular momentum, spin, parity, mag. and electr. moments, collective excitation forms, spin-orbit interaction
5. Radioactivity and spectroscopy, radioactive decay, natural and civilisation sources of ionising radiation
6. Nuclear energy, nuclear fission, nuclear reactors, nuclear fusion, star power, star development, formation of the chemical elements of hydrogen
7. Radiation and matter, interaction of radiation and matter, Bethe-Bloch formula, photoelectric effect, pair production
8. Instruments, accelerators and detectors
9. Electromagnetic interaction, differential cross section, virtual photons, Feynman graphs, exchange interaction
10. Strong interaction, quarks, gluons, colour and degree of freedom, deep-inelastic electron-proton scattering, confinement, asymptotic freedom, particle zoo, isospin, strangeness, SU (3) symmetry, antiprotons
11. Weak interaction, cracked mirror symmetries, Wu experiment, charge conjugation, time reversal, CP invariance, exchange particles, W and Z, neutrinos, neutrino vibrations
12. Standard model, three families of leptons and quarks, quark-lepton symmetry, Higgs boson, free parameters

Intended learning outcomes
The students understand the basic connections between fundamental Nuclear and Elementary Particle Physics. They have an overview of the experimental observations of Particle Physics and the theoretical models which describe them.

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

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 120 minutes)
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)
--
Module Group Supplementary Topics in Physics

(ECTS credits)
# Module Catalogue for the Subject
## Mathematical Physics
### Bachelor’s with 1 major, 180 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Introduction to Relativistic Physics and Classical Field Theory</td>
<td>11-RRF-202-m01</td>
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<td>Managing Director of the Institute of Theoretical Physics and Astrophysics</td>
<td>Faculty of Physics and Astronomy</td>
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<tr>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</table>

### Contents

Principles of the special theory of relativity, relativistic mechanics, covariant formulation in the Minkowski space, basic concepts of classical field theory using the example of the scalar field. Electrodynamics as Relativistic Field Theory, Conservation Quantities, Currents and Noether Theorem. Elements of relativistic hydrodynamics as well as elementary foundations of the general relativity theory for special metrics, e.g. black holes.

### Intended learning outcomes

Knowledge of the principles of special relativity and standard methods for solving classical relativistic problems in covariant representation. Safe handling of classical relativistic field theories as well as a rough overview of the basics of general relativity. The students should be prepared for further elective courses in theoretical physics in the Master’s program.

### Courses

<table>
<thead>
<tr>
<th>Type</th>
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<tbody>
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<tr>
<td>R</td>
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Module taught in: German or English

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

Assessment offered: Once a year, summer semester

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)
## Module Catalogue for the Subject Mathematical Physics

### Bachelor's with 1 major, 180 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Introduction to Quantum Computing and Quantum Information</td>
<td>11-QUI-202-m01</td>
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<table>
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<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
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<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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<tbody>
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</tbody>
</table>

### Contents


### Intended learning outcomes

Knowledge of the basic principles of quantum information theory and its application. Deepened understanding of specific properties of quantum systems such as entanglement. Overview of the most important theorems and possible applications of quantum information theory. The aim is to prepare the students for further elective courses on this subject in the Master’s study program.

### Courses

V (3) + R (1)

Module taught in: German or English

### Method of assessment

<table>
<thead>
<tr>
<th>(type, scope, language — if other than German)</th>
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<tr>
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<td>e) presentation/talk (approx. 30 minutes)</td>
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Language of assessment: German and/or English

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

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)
<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Group Theory</td>
<td>11-GRT-152-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**


**Intended learning outcomes**

The students know the basics of group theory, especially of Lie groups. They are able to identify problems of group theory and to solve them by using the acquired methods. They are able to apply group theory to the formulation and processing of physical problems.

**Courses**

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

V (2) + R (2)

Module taught in: German or English

**Method of assessment**

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

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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>Quantum Field Theory I</td>
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### Contents

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

### Intended learning outcomes

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

### Courses

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<tr>
<td>V (4) + R (2)</td>
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### Method of assessment

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Language of assessment: German and/or English

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

### Allocation of places

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### Additional information

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

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<tr>
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<tr>
<td>Computational Physics</td>
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</table>

**Contents**

- Introduction to programming on the basis of C++ / Java /Mathematica
- Numerical solution of differential equations
- Simulation of chaotic systems
- Generation of random numbers
- Random walk
- Many-particle processes and reaction-diffusion model

**Intended learning outcomes**

The students have knowledge of two major programming languages and know algorithms important for Physics. They have knowledge of numerical standard methods and are able to apply computer-assisted processes to the solution of physical problems, e.g. algorithms for solving numerical problems of Physics.

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

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

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

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Assessment offered: 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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<table>
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<tr>
<th><strong>Module title</strong></th>
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<tr>
<td>Statistics, Data Analysis and Computer Physics</td>
<td>11-SDC-152-m01</td>
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<tr>
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<tbody>
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<td>1 semester</td>
<td>graduate</td>
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</table>

**Contents**

Statistics, data analysis and computer physics.

**Intended learning outcomes**

The students have specific and advanced knowledge in the field of statistics, data analysis and Computational Physics.

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

V (2) + R (1)

Module taught in: German or English

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

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- Assessment offered: 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)

--
Module title | Abbreviation
---|---
Astrophysics | 11-AP-152-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 | undergraduate | --

Contents
History of astronomy, coordinates and time measurement, the Solar System, exoplanets, astronomical scales, telescopes and detectors, stellar structure and atmospheres, stellar evolution and end stages, interstellar medium, molecular clouds, structure of the milky way, the local universe, the expanding universe, galaxies, active galactic nuclei, large-scale structures, cosmology.

Intended learning outcomes
The students are familiar with the modern world view of Astrophysics. They know methods and tools for astrophysical observations and evaluations. They are able to use these methods to plan and analyse own observations. They are familiar with the physics and development of the main astrophysical objects such as stars and galaxies.

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

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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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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§ 22 II Nr. 2 f)  
§ 22 II Nr. 3 f)
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<thead>
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<th>Module title</th>
<th>Abbreviation</th>
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<td>Particle Physics (Standard Model)</td>
<td>11-TPS-152-m01</td>
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<th>Module coordinator</th>
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<td>Managing Directors of the Institute of Applied Physics and the Institute of Theoretical Physics and Astrophysics</td>
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</table>

**Contents**

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

**Intended learning outcomes**

The students know the theoretical fundamental laws of the standard model of Particle Physics and the key experiments that have established and confirmed the standard model. They are able to interpret experimental or theoretical results in the framework of the standard model and know its validity and limits.

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

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

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

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Language of assessment: German and/or English

**Allocation of places**

--

**Additional information**

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

--
Module Group Current Topics in Mathematical Physics

(ECTS credits)
### Module Catalogue for the Subject Mathematical Physics

#### Bachelor’s with 1 major, 180 ECTS credits

<table>
<thead>
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<th>Module title</th>
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<tbody>
<tr>
<td>Current Topics in Mathematical Physics</td>
<td>11-BXMP5-152-m01</td>
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</tbody>
</table>

#### Module coordinator

Chairperson of examination committee Mathematische Physik (Mathematical Physics)

#### Module offered by

Faculty of Physics and Astronomy

<table>
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<th>ECTS</th>
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</table>

#### Contents

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

#### Intended learning outcomes

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

#### Courses

<table>
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<th>Type</th>
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<td>R</td>
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#### Method of assessment

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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
Mathematical Physics
Bachelor's with 1 major, 180 ECTS credits

<table>
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### Intended learning outcomes
The students have advanced competencies corresponding to the requirements of a module of Mathematical Physics of the Bachelor’s programme. They have knowledge of a current subdiscipline of Mathematical Physics and understand the numeric and analytic 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 is creditable for bonus)

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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 Mathematical Physics**

**Abbreviation**

11-BXMP8-152-m01

### Module coordinator

Chairperson of examination committee Mathematische Physik (Mathematical Physics)

### Module offered by

Faculty of Physics and Astronomy

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

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### Duration Module level Other prerequisites

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<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
<td>Approval from examination committee required.</td>
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</table>

### Contents

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

### Intended learning outcomes

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

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

V (4) + R (2)

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

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.

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)

--
Key Skills Area
(20 ECTS credits)
General Key Skills
(5 ECTS credits)

In addition to the modules listed below, students may also take modules offered by JMU as part of the pool of general transferable skills (ASQ).
General Key Skills (subject-specific)

(ECTS credits)
<table>
<thead>
<tr>
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>Exercise tutor or proof-reading in Mathematics</td>
<td>10-M-TuKo-152-m01</td>
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<table>
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<tbody>
<tr>
<td>1 semester</td>
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<td>Please direct application to teaching coordinator Mathematics, he/she will select participants.</td>
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</table>

### Contents
Tutoring or grading homework for one of the basic courses in the Bachelor’s or teaching degree programmes under supervision of the respective lecturer or exercise supervisor.

### Intended learning outcomes
The student is able to support the acquisition of mathematical skills and knowledge. He/She helps to identify mistakes in mathematical proof exercises and to find possible solutions.

### Courses (type, number of weekly contact hours, language — if other than German)
T (0)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
Assessment of tutoring activities or correcting work by supervising lecturers or exercise supervisors (1 to 2 teaching units or approx. 5 pieces of correcting work)

### 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. 3 f)
<table>
<thead>
<tr>
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<th>Abbreviation</th>
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<tr>
<td>E-Learning and Blended Learning Mathematics 1</td>
<td>10-M-VHB1-152-m01</td>
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<tbody>
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**Contents**

Becoming familiar with and reflecting techniques in e-learning and blended learning in mathematics.

**Intended learning outcomes**

The student is able to employ basic methods of e-learning and blended learning in mathematics.

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

<table>
<thead>
<tr>
<th>Ü (2)</th>
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<tbody>
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<td>Course type: eLearning, mostly Virtuelle Hochschule Bayern (vhb)</td>
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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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**Allocation of places**

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**Additional information**

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

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<table>
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<tr>
<td>E-Learning und Blended Learning Mathematik 2</td>
<td>10-M-VHB2-152-m01</td>
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**Contents**

Becoming familiar with and reflecting techniques in e-learning and blended learning in mathematics.

**Intended learning outcomes**

The student is able to employ advanced methods of e-learning and blended learning in mathematics.

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

<table>
<thead>
<tr>
<th>Ü (2)</th>
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</table>

Course type: eLearning, mostly Virtuelle Hochschule Bayern (vhb)

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

- project (web-based, 15 to 20 hours)
- Assessment offered: Once a year, summer semester

**Allocation of places**

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**Additional information**

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

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<td>Faculty of Physics and Astronomy</td>
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<td>undergraduate</td>
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</table>

**Contents**

Mathematical basics and elementary calculus refreshing and extending knowledge from school, especially as an introduction and preparation for the modules of experimental and theoretical physics.

1. Basic geometry and algebra, 2. differential calculus and series, 3. integral calculus, 4. vectors – directional quantities, 5. coordinate systems, 6. complex numbers

**Intended learning outcomes**

Students are in command of knowledge of basic mathematics and possess skills in elementary calculus as required for the successful start into the studies of experimental and theoretical physics.

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

V (1) + Ü (2)

Module taught in: German or English

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

exercises (successful completion of approx. 50% of approx. 6 exercise sheets) or talk (approx. 15 minutes)

Assessment offered: Once a year, winter semester

**Allocation of places**

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**Additional information**

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

§ 22 II Nr. 1 h)
§ 22 II Nr. 2 f)
§ 22 II Nr. 3 f)
Subject-specific Key Skills

(15 ECTS credits)
Compulsory Courses

(9 ECTS credits)
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<td>Basic Notions and Methods of Mathematical Reasoning</td>
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<tbody>
<tr>
<td></td>
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</table>

**Contents**

Introduction to the basic notions and proof techniques in mathematics: approach to sets, formal logic and maps.

**Intended learning outcomes**

The student gets acquainted with the basic working techniques which are prerequisites for the further courses in the Bachelor’s degree study programme.

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

V (1) + Ü (1)

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

project (10 to 15 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)

§ 22 II Nr. 1 h)

§ 22 II Nr. 2 f)
<table>
<thead>
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<th>Module title</th>
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<td>Reasoning and Writing in Mathematics</td>
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Duration | Module level | Other prerequisites |
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<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</table>

Contents

Introduction to fundamental methods of thinking and proving, basic techniques in mathematics as well as mathematical writing; insight into examples of abstract concepts in mathematics; approach to axiomatic and deduction.

Intended learning outcomes

The student is acquainted with the basic proof methods and techniques in mathematics. He/She is able to perform easy mathematical arguments independently and present them adequately and reasonably in written and oral form.

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

V (1) + Ü (1)

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

project (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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<table>
<thead>
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<td>Seminar Mathematical Physics</td>
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<td>chairperson of examination committee Mathematische Physik (Mathematical Physics)</td>
<td>Faculty of Physics and Astronomy</td>
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<tbody>
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<td>1 semester</td>
<td>undergraduate</td>
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</table>

**Contents**

A selected topic of Mathematical Physics.

**Intended learning outcomes**

The students learn about the principles of independent scientific work. This involves the development and division of a given topic on the basis of literature, the preparation of a lecture as well as the ability to actively participate in discussions.

**Courses**

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

S (2)

Module taught in: German or English

**Method of assessment**

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

talk (60 to 120 minutes)

Language of assessment: German and/or English

**Allocation of places**

--

**Additional information**

--

**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

--
Subject-specific Key Skills, Compulsory Electives

(6 ECTS credits)
### Module Catalogue for the Subject
### Mathematical Physics

**Bachelor's with 1 major, 180 ECTS credits**

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Supplementary Seminar Mathematics</td>
<td>10-M-SEM2-152-m01</td>
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<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</tr>
</tbody>
</table>

### Contents

A selected topic in mathematics.

### Intended learning outcomes

The student gains first experience with independent scientific work. He/She masters elaboration and structuring of a given topic using selected literature, and prepares a talk on the subject. He/She is able to participate actively in a scientific discussion.

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

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

- Talk (60 to 120 minutes)
- 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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<table>
<thead>
<tr>
<th>Module title</th>
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<td>Seminar Experimental/Theoretical Physics</td>
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<tbody>
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<td>Managing Directors of the Institute of Applied Physics and the Institute of Theoretical Physics and Astrophysics</td>
<td>Faculty of Physics and Astronomy</td>
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<th>Other prerequisites</th>
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<tbody>
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<td>undergraduate</td>
<td>Admission prerequisite to assessment: regular attendance (minimum 85% of sessions).</td>
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**Contents**

Current issues of Theoretical/Experimental Physics.

**Intended learning outcomes**

The students have advanced knowledge of a specialist field of Experimental or Theoretical Physics. They are able to independently acquire this knowledge and to summarise it in an oral presentation.

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

S (2)

Module taught in: German or English

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

talk with discussion (30 to 45 minutes)

**Allocation of places**

--

**Additional information**

Registration: If a student registers for the exercises 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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<table>
<thead>
<tr>
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<td>10-M-TOP-152-m01</td>
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</table>

**Contents**

Basics in set-theoretic topology, topological spaces and continuity, separation properties, connectivity, examples and constructions of topological spaces, quotients, convergence of sequences and nets, different notions of compactness, additional topics (optional), e. g. the theorems of Stone-Weierstraß, Arzela-Ascoli and Baire, and introduction to algebraic topology.

**Intended learning outcomes**

The student knows the fundamental concepts and methods of topology as well as the pertinent proof methods, is able to apply methods from linear algebra and analysis to topology, and realises the broad applicability of the theory to other branches of mathematics.

**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 is creditable for 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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<table>
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<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<tbody>
<tr>
<td>1 semester</td>
<td>undergraduate</td>
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**Contents**

Introduction to modern mathematical software for symbolic computation (e.g. Mathematica or Maple) and numerical computation (e.g. Matlab) to supplement the basic modules in analysis and linear algebra (10-M-ANA-G and 10-M-LNA-G). Computer-based solution of problems in linear algebra, geometry, analysis, in particular differential and integral calculus; visualisation of functions.

**Intended learning outcomes**

The student learns the use of advanced modern mathematical software packages, and is able to assess their fields of application to solve mathematical problems.

**Courses**

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

V (1) + Ü (2)

**Method of assessment**

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

project in the form of programming exercises (approx. 20 to 25 hours)
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)

§ 22 II Nr. 3 f)
<table>
<thead>
<tr>
<th>Module title</th>
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<td>Programming course for students of Mathematics and other subjects</td>
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<td>1 semester</td>
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</table>

**Contents**
Basics of a modern programming language (e. g. C).

**Intended learning outcomes**
The student is able to work independently on small programming exercises and standard programming problems in mathematics.

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

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
Project in the form of programming exercises (approx. 20 to 25 hours)
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)
§ 22 II Nr. 3 f)
### Module title

**Selected Topics in History of Mathematics**

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<th>Abbreviation</th>
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### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

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</tbody>
</table>

### Duration

1 semester

### Module level

undergraduate

### Other prerequisites

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### Contents

Historical and cultural development as well as social relevance of mathematics; more in-depth discussion of the fundamentals of mathematics, in particular in its relation to other sciences and humanities as well as to the image of mathematics in modern society.

### Intended learning outcomes

Based on selected examples, the student has gained insight into the historical and cultural genesis of mathematical theories and their social relevance. He/she is able to present mathematical ideas and concepts to a general audience.

### Courses

V (2) + Ü (2)

### Method of assessment

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

a) talk (45 to 90 minutes) or b) term paper (10 to 15 pages) or c) project (15 to 25 hours)

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)

§ 22 II Nr. 3 f)
Module title: Mathematical Writing

Abbreviation: 10-M-MSC-152-m01

Module coordinator: Dean of Studies Mathematik (Mathematics)

Module offered by: Institute of Mathematics

ECTS: 5

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

Method of grading: (not) successfully completed --

Duration: 1 semester

Module level: undergraduate

Other prerequisites: --

Contents:
Discussion of good and bad mathematical writing using practical exercises and case examples. The course covers the whole range of mathematical texts from short proofs and the formulation of theorems and definitions to comprehensive works such as Bachelor's or Master's theses. Important aspects include not only mathematical rigour and efficiency but also didactic questions.

Intended learning outcomes:
The student is able to formulate mathematical subject matter precisely and comprehensibly. He/She knows about the structures and conventions of mathematical literature and the requirements of scientific work.

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 is creditable for bonus)
a) talk (45 to 90 minutes) or b) term paper (10 to 15 pages) or c) project (15 to 25 hours)
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)
§ 22 II Nr. 3 f)

Bachelor's with 1 major Mathematical Physics

(2020)
<table>
<thead>
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<th>Module title</th>
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<td>School Mathematics from a Higher Perspective</td>
<td>10-M-SCH-152-m01</td>
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<th>Other prerequisites</th>
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<td>1 semester</td>
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</table>

**Contents**

Discussion of selected topics in school mathematics with respect to their integration into wider theories and their didactic implementation at both school and university levels.

**Intended learning outcomes**

By means of selected examples, the student gains insight into the interaction between school mathematics and advanced mathematical theories. He/She is able to discuss these under mathematical, didactical and methodical aspect.

**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 is creditable for bonus)

- a) talk (approx. 45 minutes) or b) term paper (10 to 15 pages) or c) project (15 to 25 hours)
- 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)

- § 22 II Nr. 1 h)
- § 22 II Nr. 2 f)
- § 22 II Nr. 3 f)
<table>
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<td>Proseminar Mathematics</td>
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<tr>
<td>1 semester</td>
<td>undergraduate</td>
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</table>

**Contents**

Selected basic topics in mathematics.

**Intended learning outcomes**

The student gains first experience with independent scientific work. He/She masters elaboration and structuring of a given topic using selected literature, and prepares a talk on the subject. He/She is able to participate actively in a scientific discussion.

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

S (2)

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

Talk (60 to 120 minutes)

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

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>Managing Director of the Institute of Theoretical Physics and Astrophysics</td>
<td>Faculty of Physics and Astronomy</td>
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<td>2 semester</td>
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**Contents**

German contents available but not translated yet.

Grundlagen der Mathematik und elementare Rechenmethoden jenseits des Schulstoffes, insbesondere zur Einführung und Vorbereitung auf die Module der Theoretischen Physik und der Klassischen bzw. Experimentellen Physik

**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Der/Die Studierende verfügt über die Kenntnisse der Grundlagen der Mathematik und der elementaren Rechen-techniken, welche in der Theoretischen Physik und der Experimentellen Physik benötigt werden.

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

V (2) + Ü (2) + V (2) + Ü (2)

Module taught in: German or English

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

Exercises (successful completion of approx. 50% of approx. 13 exercise sheets) or Talk (approx. 15 minutes)

**Allocation of places**

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**Additional information**

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

§ 53 I Nr. 1 a)

§ 77 I Nr. 1 a)
<table>
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**Contents**

- Introduction to programming on the basis of C++ / Java /Mathematica
- numerical solution of differential equations
- simulation of chaotic systems
- generation of random numbers
- random walk
- many-particle processes and reaction-diffusion model

**Intended learning outcomes**

The students have knowledge of two major programming languages and know algorithms important for Physics. They have knowledge of numerical standard methods and are able to apply computer-assisted processes to the solution of physical problems, e.g. algorithms for solving numerical problems of Physics.

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

V (3) + R (1)

Module taught in: German or English

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

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: 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)

--
Thesis
(10 ECTS credits)
## Module Catalogue for the Subject Mathematical Physics

**Bachelor's with 1 major, 180 ECTS credits**

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<th>Module title</th>
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<td>Bachelor Thesis Mathematical Physics</td>
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### ECTS  | Method of grading | Only after succ. compl. of module(s) |
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<td></td>
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<td>Where applicable, topic-specific modules as specified by supervisor.</td>
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## Contents

Independently researching and writing on a (potentially interdisciplinary) topic in mathematics or physics selected in consultation with the supervisor.

## Intended learning outcomes

The student is able to work independently on a given, possibly interdisciplinary topic in mathematics or physics and apply the skills and methods obtained during the study programme. He/She can write down the result of his/her work in a suitable form.

## Courses

No courses assigned to module

## Method of assessment

**written thesis (approx. 250 to 300 hours total)**

## 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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