**Brandenburgische Technische Universität Cottbus - Senftenberg**
**Platz der Deutschen Einheit 1, 03046 Cottbus**

# Modulhandbuch für den Studiengang Physics (universitäres Profil), Master of Science, Prüfungsordnung 2021

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# Module 13012 Advanced Seminar Experimental Physics

assign to: Specialization Phase

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13012 | Mandatory |

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|---|---|
| **Modul Title** | **Advanced Seminar Experimental Physics**<br>Hauptseminar Experimentelle Physik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Flege, Jan Ingo |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are able to prepare and orally present a detailed scientific topic, including an autonomous familiarization with a given scientific problem in experimental physics and the comprehensible oral presentation of a complex topic in a limited time, using well-arranged foils (e.g. power point). Additionally, the ability to participate in a scientific discussions was promoted. |
| **Contents** | Individual presentations in selected topics of experimental physics. |
| **Recommended Prerequisites** | • Sound knowledge of physics at or beyond the bachelor level. |
| **Mandatory Prerequisites** | Sound knowledge of physics at or beyond the bachelor level. |
| **Forms of Teaching and Proportion** | Seminar - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | Specific literature, depending on the topic, will be provided at the beginning of the seminar. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Seminar talk, 30-45 min. depending on the topic (70%)<br>• Active participation in seminar course (30%)<br><br>75% are required to pass the module. |
| **Evaluation of Module Examination** | Performance Verification – graded |

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|---|---|
| **Limited Number of Participants** | 8 |
| **Remarks** | • Study programme Physics M.Sc.: Mandatory module<br><br>Self organised studies comprise:<br>• reworking of talks<br>• preparation of a scientific presentation<br><br>The participant limit applies per course offered. |
| **Module Components** | • Seminars in the field of „Experimental Physics“, to be chosen from the current offer. |
| **Components to be offered in the Current Semester** | **150340** Seminar<br>Advanced Seminar Experimental Physics - 2 Hours per Term<br>**150430** Seminar<br>Nano-Photonics - 2 Hours per Term<br>**152230** Seminar<br>Functional material systems for micro sensors and actuators |

# Module 13014 Advanced Seminar Theoretical Physics

assign to: Specialization Phase

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13014 | Mandatory |

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|---|---|
| **Modul Title** | **Advanced Seminar Theoretical Physics**<br>Hauptseminar Theoretische Physik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Gorelova, Darya |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are able to prepare and orally present a detailed scientific topic, including an autonomous familiarization with a given scientific problem in experimental physics and the comprehensible oral presentation of a complex topic in a limited time, using well-arranged slides (e.g. power point). Additionally, the ability to participate in a scientific discussions is promoted. |
| **Contents** | Individual presentations in selected topics of theoretical physics. |
| **Recommended Prerequisites** | • Sound knowledge of physics at or beyond the bachelor level. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Seminar - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | Specific literature, depending on the topic, will be provided at the beginning of the seminar. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Seminar talk, 30-45 min. depending on the topic (70%)<br>• Active participation in seminar course (30%)<br><br>75% are required to pass the module. |
| **Evaluation of Module Examination** | Performance Verification – graded |

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|---|---|
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Mandatory module<br><br>Self organised studies comprise:<br>• reworking of talks<br>• preparation of a scientific presentation |
| **Module Components** | • Seminars in the field of „Theoretical Physics“, to be chosen from the current offer. |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13023 Introduction to Semiconductor Physics

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13023 | Compulsory elective |

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|---|---|
| **Modul Title** | **Introduction to Semiconductor Physics**<br>Einführung in die Halbleiterphysik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | Students comprehend basic concepts, models and methods in the field of semiconductor physics and application. They recognize the connections between basic physical research and semiconductor technology based on the range of topics of the lecture and have gained insight into semiconductor research topics of BTU Cottbus – Senftenberg. |
| **Contents** | Starting with a basic presentation of semiconductor physics, the most important semiconductor devices will be presented. The central technologies for their production will be discussed.<br>• Semiconductor physics: band model, doping, semiclassical description, drift diffusion model<br>• Semiconductor technology: crystal growth, wafer fabrication, doping techniques, structuring techniques<br>• Devices: pn-junction, LEDs, MIS structure, bipolar and field effect transistor, solar cell<br><br>Self organised studies include:<br>• discussion of a research paper<br>• working out of exercises |
| **Recommended Prerequisites** | • Knowledge of Theoretical Physics and Mathematics at the third year of the Physics Bachelor. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester |

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|---|---|
| | Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • S. M. Sze: Semiconductor Devices<br>• P. Yu, M. Cardona: Fundamentals of Semiconductors<br>• Supriyo Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 90 min. **OR**<br>• Oral examination, 30-45 min. (in case of small number of participants)<br><br>In the first lecture the examination form will be announced. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Physik B.Sc.: Compulsory elective module in the complex „Physical Specialised Module“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in the complex „Applications: Natural Sciences and Engineering“<br><br>Self organised studies comprise:<br>• reworking of the lecture<br>• discussion of a research paper<br>• working out of exercises |
| **Module Components** | • Lecture: Introduction to Semiconductor Physics<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13038 Nanoelectronics

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13038 | Compulsory elective |

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|---|---|
| **Modul Title** | **Nanoelectronics**<br>Nanoelektronik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students master the basics of nanoelectronics especially methods of acquiring knowledge as well as their exemplified application. Furthermore, social skills of the students as accuracy, perseverance, curiosity, own initiative etc. have been promoted. |
| **Contents** | We discuss the physics of the most important nanoelectronic devices:<br>• resonant tunneling diode<br>• nano-FET (nano field-effect transistor)<br>• laser diode<br><br>For each of these devices a basic quantum mechanical description is derived. Subsequently the numerical evaluation of the theory is demonstrated. In the exercices the student learns to apply existing software solutions. The calculated characteristics will be compared with experimental results. In a more detailed treatment elements of advanced quantum mechanics are introduced. These are the application of Greens functions or Fermi's golden rule. |
| **Recommended Prerequisites** | Knowledge of basic quantum mechanics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |

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|---|---|
| **Teaching Materials and Literature** | • Supriyo Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br><br>Self-contained studies comprise:<br>• reworking of the lecture<br>• reading of scietific literature<br>• solving of exercises |
| **Module Components** | • Lecture: Nanoelectronics<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13026 Solid State Theory

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13026 | Compulsory elective |

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|---|---|
| **Modul Title** | **Solid State Theory**<br>Festkörpertheorie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have acquired basic knowledge in solid state theory with regard to formal aspects and modelling. The topic of the module serves as an example to illustrate the connection between basic and applied science and to demonstrate the methods of attaining new perceptions. Additionally the module supports presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | • Electronic states in solids, band theory<br>• Methods of Band Structure Calculation<br>• Linear response theory, application to collective excitations in solids: plasmons, optical conductivity, dielectric function<br>• Transport: Boltzmann equation and applications, scattering rates, impurities<br>• Elastic properties of solids |
| **Recommended Prerequisites** | • Basic (at Bachelor level) knowledge of solid state physics and theoretical physics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • O. Madelung: Introduction to Solid-State Theory |

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|---|---|
| | • R. M. Martin, Electronic structure: Theory and practical methods<br>• G. D. Mahan, Many Particle Physics |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments (75% must be reached)<br><br>**Final module examination:**<br>• Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with theoretical focus“, topic area „Condensed Matter Physics“<br><br>Self-contained studies comprise:<br>• reworking of the lecture<br>• solving of exercises<br>• preparation of a presentation based on a given scientific paper<br><br>**Please confirm actual module offer in time (during preparation of the stady plan at the beginning of the 1st semester) with the module responsible!** |
| **Module Components** | • Lecture: Solid State Theory<br>• Accompanying seminar (journal club)<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | **150190** Lecture<br>Solid State Theory - 2 Hours per Term<br>**150191** Exercise<br>Solid State Theory - 2 Hours per Term<br>**150192** Seminar<br>Solid State Theory - 2 Hours per Term<br>**150193** Examination<br>Solid State Theory |

# Module 14846 Principles of Superconductivity

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14846 | Compulsory elective |

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|---|---|
| **Modul Title** | **Principles of Superconductivity**<br>Grundlagen der Supraleitung |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have acquired basic knowledge in the physics of superconductivity with regard to theoretical and phenomenological aspects. They understand the connection between basic and applied science and know methods of attaining new perceptions. Additionally the module supports presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | • Experimental and theoretical foundations of superconductivity, phenomenological description: London and Ginzburg-Landau theories, Superconductors in a magnetic field, Josephson effects.<br>• Microscopic description: pairing mechanism, Cooper problem, BCS theory, tunneling effects.<br>• New developments: high Tc superconductivity. |
| **Recommended Prerequisites** | • Knowledge of solid state physics and theoretical physics at bachelor level. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • W. Buckel, R. Kleiner: Superconductivity: Fundamentals and Applications<br>• M. Thinkam, Introduction to Superconductivity, Krieger Publishing<br>• D. Gennes, Superconductivity of Metals and Alloys, Addison Wesley |

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|---|---|
| | • J. R. Shrieffer, Theory of Superconductivity, Addison Wesley |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments<br><br>**Final module examination:**<br>• Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“ |
| **Module Components** | • Lecture: Principles of Superconductivity<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13010 General Theory of Relativity

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13010 | Compulsory elective |

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|---|---|
| **Modul Title** | **General Theory of Relativity**<br>Allgemeine Relativitätstheorie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students know the idea of space-time and its characterization. Besides the concepts of Quantum Theory it plays a fundamental role for the understanding of modern physics. As a typical theoretical field it summarizes and explains different known facts on the basis of a few very general principles, it reflects an important working method of theoretical physics. Additionally the module supports presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | Galilei space, Minkowski space, Riemannian space, curved space-time, general relativistic effects, cosmological models. |
| **Recommended Prerequisites** | • Knowledge of theoretical mechanics and electrodynamics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Ray D'inverno: Introducing Einstein's Relativity<br>• L.H. Ryder: Introduction to General Relativity<br>• W. Rindler, Relativity: Special, General and Cosmological |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • oral examination, 30-45 Minuten |

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| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with theoretical focus“, topic area „Theory, Simulation and further topics“<br>• Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Applications“, field „Physics“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Applications: Natural Sciences and Engineering“<br><br>Self organised studies consist of:<br>• revise lectures<br>• study handouts and solve problems<br>• weekly issued working sheets are given to students for deeping of knowledge<br><br>**Due to the offer on special announcement please check in time (in the preparation of the Master Plan at the beginning of the first semester) the specific module offer with the responsibel staff member!** |
| **Module Components** | • Lecture: General Theory of Relativity<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13440 Waves and Instabilities in Fluids

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13440 | Compulsory elective |

| | |
|---|---|
| **Modul Title** | **Waves and Instabilities in Fluids**<br>Wellen und Instabilitäten in Flüssigkeiten |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | PD Dr. rer. nat. habil. Borcia, Rodica |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students master the foundations of hydrodynamics with regard to theoretical and phenomenological aspects. The topic of the module serves as an example for studying the realization of knowledge and the classification of knowledge within the field of physics.<br>In addition the module supports further competences as e. g. cooperation ability, carefullness, persistance, curiosity, working on one's own initiative. |
| **Contents** | 1. Hydrodynamic basic equations: Euler, Navier-Stokes, continuity, energy, concentration(s)<br>2. Surface waves: Potential flow, deep and shallow water, solitons, Tsunamis, capillary waves<br>3. Instabilities: general principles, bifurcation theory, classification<br>4. Unstable systems: Kelvin-Helmhotz, Rayleigh-Taylor, convection, mixtures, thin films |
| **Recommended Prerequisites** | • Basic level knowledge in theoretical physics (Bachelor-level) |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • P. K. Kundi, Fluid Mechanics<br>• H. Lamb, Hydrodynamics |

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|---|---|
| | • T. E. Faber, Fluid Dynamics for Physicists |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments (75% must be reached)<br><br>**Final module examination:**<br>• Written examination, 90 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with theoretical focus“, topic area „Theory, Simulation and further topics“<br>• Study programme Applied Mathematics M.Sc.: Compulsory elective module in complex „Applications“, field „Physics“ |
| **Module Components** | • Lecture: Waves and Instabilities in Fluids<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **150120** Lecture<br>Waves and Instabilities in Fluids - 2 Hours per Term<br>**150121** Exercise<br>Waves and Instabilities in Fluids - 2 Hours per Term<br>**150123** Examination<br>Waves and Instabilities in Fluids |

# Module 13944 Quantum Electrodynamics

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13944 | Compulsory elective |

| | |
|---|---|
| **Modul Title** | **Quantum Electrodynamics**<br>Quantenelektrodynamik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will have developed a solid understanding of quantum electrodynamics as a fundamental model of modern relativistic quantum field theories and they can apply the knowledge they have acquired to describe the interaction between electrons and photons. Using the module's topic as an example, they know the methods of gaining knowledge, the classification of physical findings in the overall context, and the interconnection of individual findings. In addition, individual competencies such as diligence, perseverance, curiosity, initiative, etc. were promoted by the students. |
| **Contents** | • Canonical field quantization<br>• Quantization of the electromagnetic field<br>• Second quantization of the electron field<br>• Light-Matter Interaction |
| **Recommended Prerequisites** | Knowledge of theoretical physics - in particular quantum mechanics- in the frame of bachelor studies. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Franz Gross, Relativistic Quantum Mechanics and Quantum Field Theory<br>• H. Haken, Light and Matter |

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|---|---|
| | • W. Greiner, Quantum Electrodynamics |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with theoretical focus“, topic area „Theory, Simulation and further topics“<br>• Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in field of application „Physik“ |
| **Module Components** | • Lecture: Quantum Electrodynamics<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14289 Computational Quantum Physics

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14289 | Compulsory elective |

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|---|---|
| **Modul Title** | **Computational Quantum Physics**<br>Computergestützte Quantenphysik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Gorelova, Darya |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be able to solve complex physical problems by means of computer coding and simulations. Students are familiar with various numerical methods that are used in quantum mechanics, as well as in other fields. Students are extensively experienced in writing codes for solving problems numerically. Students have in-depth knowledge of quantum mechanics and can deal with quantum dynamical processes. |
| **Contents** | Numerical approaches:Lancos algorithm, Monte Carlo algorithm, Machine Learning, Numerov algorithm, Cranck-Nicolson Algorithm, Runge-Kutta algorithm, etc. Approximate solutions of the time-dependent Schrödinger equation. Calculations of the temporal evolution of a wave-function, electron density, spin state, spectra, taking into account decoherence.Programming languages: C++ or python. |
| **Recommended Prerequisites** | Knowledge of quantum mechanics on the level of a physics bachelor. Knowledge of C++ or python. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Philipp O.J. Scherer. *Computational Physics. Simulation of Classical and Quantum Systems.* |

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| | • Rubin H. Landau, Manuel Jose Paez, Cristian C. Bordeianu. *Computational Physics. Problem Solving with Computers.*<br>• Jos Thijssen. *Computational Physics.*<br>• Joshua Izaac and Jingbo Wang. *Computational Quantum Mechanics.*<br>• Tannor, David J. *Introduction to Quantum Mechanics: A Time-Dependent Perspective.*<br>• F. Grossmann. *Theoretical Femtosecond Physics. Atoms and Molecules in Strong Laser Fields.* |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of of exercise assignments (50% must be reached)<br><br>**Final module examination:**<br>• Written examination, 90 min. (Solving tasks on the computer ) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“, topic area „Theory, Simulation and further topics“ |
| **Module Components** | • Lecture: Computational Quantum Physics<br>• Accompyning exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | **150230** Lecture<br>Computational Quantum Physics - 2 Hours per Term<br>**150231** Exercise<br>Computational Quantum Physics - 2 Hours per Term<br>**150232** Examination<br>Computational Quantum Physics |

# Module 14499 Light and Matter: Quantum

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14499 | Compulsory elective |

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|---|---|
| **Modul Title** | **Light and Matter: Quantum**<br>Licht und Materie: Quantum |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Gorelova, Darya |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have acquired knowledge of quantum-mechanical description of light-induced processes. They have achieved a conceptual and quantitative understanding of microscopic processes behind interaction of atoms, molecules and materials with light. They know about modern ultrafast light-induced phenomena. |
| **Contents** | Quantization of an electromagnetic field, examples for electromagnetic states, application of perturbation theory to the interaction of electromagnetic fields with matter, absorption, scattering and emission of photons, photoionization, interaction with x-ray light, relaxation processes, state lifetime, nonperturbative light-matter interaction, Floquet theory. |
| **Recommended Prerequisites** | Knowledge of quantum mechanics on the level of a physics bachelor |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • F. Grossmann. *Theoretical Femtosecond Physics. Atoms and Molecules in Strong Laser Fields.*<br>• Stefan P. Hau-Riege. *Nonrelativistic Quantum X-Ray Physics*<br>• Loudon R. *The Quantum Theory of Light* |

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| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments (50% must be reached) and presentation<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30-45 min. (depending on the number of student attendees)<br><br>The choice of exam (written, oral) will be announced in the first lecture. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“, topic area „Theory, Simulation and Further Topics“ |
| **Module Components** | • Lecture: Light and Matter: Quantum  Current Description<br>• Accompanying exercise<br>• Accompanying seminar: journal club<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 11222 Photovoltaics: Basics, State of the Art and Solar Cell Materials Research

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11222 | Compulsory elective |

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|---|---|
| **Modul Title** | **Photovoltaics: Basics, State of the Art and Solar Cell Materials Research**<br>Photovoltaik: Grundlagen, Stand der Technik und PV-Materialforschung |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | apl. Prof. Dr. sc. nat. Kittler, Martin |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have obtained an introduction into photovoltaics, including the basics of the fundamental principles of operation and fabrication of solar cells. Furthermore, current photovoltaic technology trends and materials research towards new concepts have been discussed. Additionally the module supports presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | 1. Insolation: Energy sources for photovoltaics<br>2. Crash course in semiconductor physics:<br>(a) Absorption<br>(b) Electrons and holes in semiconductors<br>(c) Generation, transport and recombination of charge carriers<br>(d) p-n junction under illumination<br>3. Photovoltaic technologies (Si-wafer based vs. Thin-Film PV)<br>4. Solar cell materials |
| **Recommended Prerequisites** | • Fundamental knowlegde in physics and engineering (e.g. a bachelor's degree program in physics) |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | Copies of viewgraphs will be made available.<br>Suggested literature:<br>• A.L.Fahrenbruch, R.H.Bube, "Fundamentals of Solar Cells", Academic Press, New York - London 1983<br>• H.J.Möller, "Semiconductors of Solar Cells", Artech House, Boston - London 1993<br>• S.M.Sze, Chapter 14 in "Physics of Semiconductor Devices", John Wiley & Sons, New York 1981 |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination (90 min.) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“ |
| **Module Components** | • Lecture: Photovoltaics: Basics, State of the Art and Solar Cell Materials Research<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13009 Semiconductor Technology

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13009 | Compulsory elective |

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|---|---|
| **Modul Title** | **Semiconductor Technology**<br>Halbleitertechnologie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Kahmen, Gerhard |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have learned the fundamentals of semiconductor physics, the topology and functionality of key semiconductor devices and seminconductor munufacturing processes to realize integrated silicon-based circuits. They have gained an insight into the adjacent fields of material and device diagnostics, manufacturing process control and an overview of technological trends in the semiconductor industry. The knowledge gained from this course enables the students to evaluate given semiconductor technologies with regard to their suitability for apllication, e.g. in electronic circuits and systems. |
| **Contents** | • Historical overview of the development of semiconductor technology and semiconductor market<br>• Semiconductor physics basics<br>• Basics of integrated semiconductor devices (passives, diode, bipolartransistor, FET)<br>• Si crystal lattice, crystal growth, wafer production, doping and contamination of wafer material<br>• Oxidation<br>• Doping by diffusion and implantation<br>• Layer deposition and Epitaxial growth of crystalline Si(Ge) layers on the substrate<br>• Structuring by lithography, etching process<br>• Cleaning and planarization processes<br>• Silicon on insulator (SOI)<br>• Diagnostics, process control & Metrology for Si-based semiconductor processes |

- Outlook on future semiconductor technologies
- Excursion to visit semiconductor FAB at IHP-Leibniz Institute for High Performance Microelectronics

**Recommended Prerequisites**

- Knowledge of semiconductor physics based on the bachelor degree in physics, in particular knowledge of the content of module 11868: Allgemeine Physik IV (Festkörperphysik)
- Knowledge of the functioning and structure of electronic components, such as knowledge of the content of module 12364: Elektronische Bauelemente und Grundschaltungen
- Knowledge of solid-state physics or electrical engineering at a level corresponding to the first four semesters of a Bachelor's degree in physics or electrical engineering

**Mandatory Prerequisites**

none

**Forms of Teaching and Proportion**

Lecture - 2 hours per week per semester
Study project - 30 hours
Self organised studies - 120 hours

**Teaching Materials and Literature**

Teaching material will be provided before each lecture

Recommended Literature:

- S.M. Sze, „Physics of Semiconductor Devices“, John Wiley & Sons, 3rd Edition, 2008
- R. Doering, Y. Nishi, “Handbook of Semiconductor Manufacturing Technology”, CRC Press, 2nd Edition, 2008
- P.R. Gray, P.J. Hurst, S.H. Lewis, R.G. Meyer, „Analysis and Design of Analog Integrated Circuits“, John Whiley & Sons, 4th Edition, 2001
- S. Dimirijev, „Understanding Semiconductor Devices“, Oxford University Press, 2nd Edition
- J.D. Cressler, G. Niu, „Silicon-Germanium Heterojunction Bipolar Transistors“, Artech House, 2003
- D. A. Neamen, „Semiconductor Physics and Devices“, Mc Graw Hill, Fourth Edition, 2012

**Module Examination**

Prerequisite + Final Module Examination (MAP)

**Assessment Mode for Module Examination**

**Prerequisite:**

- Successful elaboration and presentation of Homework / Study, 10-15 min.

**Final module examination:**

- Oral examination, 45 min. OR
- Written examination, 120 min. (for large numbers of participants)

In the first lecture it will be announced, wheter the examination will be organised in written or oral form.

**Evaluation of Module Examination**

Performance Verification – graded

**Limited Number of Participants**

none

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| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Informatik M.Sc.: Compulsory elective module in minor „Maschinenbau/Elektrotechnik“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“ |
| **Module Components** | • Lecture Semiconductor Technology<br>• Related examination |
| **Components to be offered in the Current Semester** | **112210** Lecture/Exercise<br>Semiconductor Technology - 2 Hours per Term<br>**112211** Examination<br>Semiconductor Technology |

# Module 13017 Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13017 | Compulsory elective |

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|---|---|
| **Modul Title** | **Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations**<br>Mikrowellen- und Millimeterwellensensoren für die Biomedizin: Anwendungen und physikalische Grundlagen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wenger, Christian |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | Students are familiar with the basic concepts of microwave and millimeter wave sensors in biomedicine. They know how to apply and focus their wide-ranging knowledge from the basic studies to a current field of research and development.<br>In addition, the students have consolidated additional skills such as cooperation, accurateness, perseverance, curiosity, initiative, frustration tolerance and the like. |
| **Contents** | **Measurement and circuit fundamentals for high-frequency (HF) sensors**<br>• Scattering parameters<br>• HF wires: features and models<br>• Antennas as near-field and far-field sensors<br>• Resonators<br>• Electric interferometers<br>• Transceiver<br>• Vector network analyzers (VNA) and power detectors<br><br>**Dielectric properties of materials in biomedicine**<br>• Dielectric properties of mixtures (binary, disperse)<br>• Dielectric properties of cells<br>• EEffective permittivity of layered materials<br>• Dielectric phantoms for emulating human tissue |

**Integrated HF Sensors for Biomedicine**
- Colpitts oscillator for classifying plaque in arteries
- Open coaxial cable with VNA as dielectric sensor
- Metamaterial resonator for measuring alcohol concentration
- Interferometer as cytometer
- On-Chip Transducer with integrated Microfluidics for Lab-on-Chip
- Millimeter wave transceiver for gas spectroscopy
- Reflectometer for measuring the dehydration of the skin

**Content Laboratory**
- Getting familiar with the design and simulation software ADS (Keysight)
- Design of wire-based dielectric sensors on printed circuit boards in the millimeter wave range
- Measurement of liquid materials using self-developed sensors and evaluation based on dielectric models
- Comparison measurements with a continuous wave interferometer
- On-Wafer measurements of existing integrated sensors and evaluation

**Recommended Prerequisites**
- Knowledge of the content of the modules in experimental physics.

**Mandatory Prerequisites**
none

**Forms of Teaching and Proportion**
Lecture - 2 hours per week per semester
Exercise - 2 hours per week per semester
Self organised studies - 120 hours

**Teaching Materials and Literature**
- Pozar, D. M. (2009). Microwave engineering. John Wiley & Sons.
- Razavi, B. (2008), Fundamentals of microelectronics. Wiley.
- Razavi, B. & Behzad, R. (1998). RF microelectronics (Vol. 2). New Jersey: Prentice Hall
- Niknejad, A. M. & Hashemi, H. (Eds.). (2008). mm-Wave silicon technology: 60 GHz and beyond. Springer Science & Business Media
- Vander Vorst, A., Rosen, A., & Kotsuka, Y. (2006). RF/microwave interaction with biological tissues (Vol. 181). John Wiley & Sons.

Training materials, measuring equipment and simulation software will be provided.

**Module Examination**
Final Module Examination (MAP)

**Assessment Mode for Module Examination**
- Oral examination 30-45 minutes

**Evaluation of Module Examination**
Performance Verification – graded

**Limited Number of Participants**
none

**Remarks**
- Study programme Physics B.Sc.: Compulsory elective module in complex „Physical Specialised Module“
- Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“

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| **Module Components** | • Lecture: Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13019 Micro Systems

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13019 | Compulsory elective |

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|---|---|
| **Modul Title** | **Micro Systems**<br>Mikrosystemtechnik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr. rer. nat. habil. Schenk, Harald |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the module, the students master the basics of silicon-based microsystems technology. Using the module's topic as an example, they understand the methods of gaining knowledge and know exemplary applications.<br>In addition, social competences such as the ability to cooperate, as well as other individual competences such as diligence, perseverance, curiosity, initiative, frustration tolerance, etc. were promoted in the students. |
| **Contents** | • Introduction to silicon technology:<br>materials, film deposition and structuring, surface- and volume-micromechanics, overview of equipment technology.<br>• Physical principles of efficiency:<br>basic physical principles of efficiency of simple sensors and actors (e.g. electrostatic, piezoelectric and magnetic effects).<br>• Proposal of complex sensors and actors:<br>overview of systematics and methodology, simple simulation examples for the calculation of dynamic properties of MEMS sensors.<br>• Function and properties of complex sensors and actors:<br>e.g. light modulators, acceleration sensors, gyroscope, scanner mirror. |
| **Recommended Prerequisites** | • Sound knowledge of solid state physics at or beyond the bachelor level. |
| **Mandatory Prerequisites** | none |

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| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 1 hours per week per semester<br>Self organised studies - 135 hours |
| **Teaching Materials and Literature** | • M. Madou, "Fundamentals of Microfabrication„, CRC Press , Boca Raton-NewYork (2002)<br>• Gianchandani, Yogesh B.; Tabata, Osamu; Zappe, Hans P.: „Comprehensive Microsystems“, Vol. 1-3, Elsevier, Amsterdam (2008)<br><br>A detailed bibliography will be provided in the first lecture. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 90 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self-organized studies are composed of:<br>• reworking of lecture<br>• literature work<br>• preparation of a talk |
| **Module Components** | • Lecture: Micro Systems<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **152210** Lecture<br>Micro Systems - 2 Hours per Term<br>**152211** Exercise<br>Micro Systems - 1 Hours per Term<br>**152212** Examination<br>Micro Systems |

# Module 13020 Laboratory Techniques and Metrology

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13020 | Compulsory elective |

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|---|---|
| **Modul Title** | **Laboratory Techniques and Metrology**<br>Labor- und Messtechnik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr. rer. nat. habil. Schenk, Harald |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have acquired an adequate and structured professional and general knowledge about the field of modern laboratory techniques and metrologies and have learned how to connect various concepts of this field.<br>Moreover, social competences like cooperation capacity and individual competencies like accuracy, perseverance, curiosity, own initiative, tolerance against frustration have been supported. |
| **Contents** | Ray optical and wave optical description of optical systems including introduction to Fourier-Optics to describe the performance of optical metrology systems Principle, properties and use of<br>• Laser vibrometer<br>• White light interferometer<br>• Ellipsometer<br>• Scanning Electron Microscopy<br>• Energy Dispersive X-Ray Spectroscopy<br>• Profilometer<br>• Nanointendation<br>• Lock-In amplifier |
| **Recommended Prerequisites** | • Basic knowledge in physics (optics, electromagnetism) and electrical engineering |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 1 hours per week per semester |

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| | Self organised studies - 135 hours |
| **Teaching Materials and Literature** | • List of literature will be presented at first lecture. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • seminar talk, 20 minutes, with written part, 10 pages (50%)<br>• written exam, 75 minutes (50%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 10 |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro-and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“ |
| **Module Components** | • Lecture: Laboratory Techniques and Metrology<br>• Accompanying seminar<br>• Related examination |
| **Components to be offered in the Current Semester** | **152220** Lecture<br>Laboratory Techniques and Metrology - 2 Hours per Term<br>**152221** Exercise<br>Laboratory Techniques and Metrology - 1 Hours per Term<br>**152222** Examination<br>Laboratory Techniques and Metrology (Re-examination only) |

# Module 13023 Introduction to Semiconductor Physics

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13023 | Compulsory elective |

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|---|---|
| **Modul Title** | **Introduction to Semiconductor Physics**<br>Einführung in die Halbleiterphysik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | Students comprehend basic concepts, models and methods in the field of semiconductor physics and application. They recognize the connections between basic physical research and semiconductor technology based on the range of topics of the lecture and have gained insight into semiconductor research topics of BTU Cottbus – Senftenberg. |
| **Contents** | Starting with a basic presentation of semiconductor physics, the most important semiconductor devices will be presented. The central technologies for their production will be discussed.<br>• Semiconductor physics: band model, doping, semiclassical description, drift diffusion model<br>• Semiconductor technology: crystal growth, wafer fabrication, doping techniques, structuring techniques<br>• Devices: pn-junction, LEDs, MIS structure, bipolar and field effect transistor, solar cell<br><br>Self organised studies include:<br>• discussion of a research paper<br>• working out of exercises |
| **Recommended Prerequisites** | • Knowledge of Theoretical Physics and Mathematics at the third year of the Physics Bachelor. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester |

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|---|---|
| | Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • S. M. Sze: Semiconductor Devices<br>• P. Yu, M. Cardona: Fundamentals of Semiconductors<br>• Supriyo Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 90 min. **OR**<br>• Oral examination, 30-45 min. (in case of small number of participants)<br><br>In the first lecture the examination form will be announced. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Physik B.Sc.: Compulsory elective module in the complex „Physical Specialised Module“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in the complex „Applications: Natural Sciences and Engineering“<br><br>Self organised studies comprise:<br>• reworking of the lecture<br>• discussion of a research paper<br>• working out of exercises |
| **Module Components** | • Lecture: Introduction to Semiconductor Physics<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13024 Light and Matter: Introduction

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13024 | Compulsory elective |

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|---|---|
| **Modul Title** | **Light and Matter: Introduction**<br>Licht und Materie: Grundlagen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Fischer, Inga Anita |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are acquainted with the foundations of light-matter interaction as well as selected applications in material analysis. They not only know how to acquire scientific knowledge but are also able to place physical phenomena into a more general context while exploring links between the different topics. In addition, students possess personal skills such as the capability for teamwork, precise reasoning, perseverance and openmindedness. |
| **Contents** | • Review of selected phenomena (including refraction, absorption, spectral lines, black body radiation, idealized climate model)<br>• Optical spectroscopy<br>• Drude-Lorentz model<br>• Electromagnetic waves at interfaces<br>• Nonlinear optics<br>• Laser<br>• Nonclassical light<br>• Concepts of quantum photonics |
| **Recommended Prerequisites** | • Knowledge of physics at or beyond the bachelor level |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 90 hours |

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| **Teaching Materials and Literature** | Will be announced during the first lecture: textbooks, scientific publications. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Calculate exercise tasks on at least two exercise dates<br><br>**Final module examination:**<br>• Written examination, 90 min.<br><br>alternatively, depending on the number of student attendees, and by arrangement:<br>• an oral examination, 30-45 min. **OR**<br>• a presentation, 30-45 min.<br><br>are possible.<br><br>The choice of form (written , oral exam or presentation) will be announced in the first lecture. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics B.Sc.: Compulsory elective module in complex „Physical Specialised Module“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self-study comprises revising the lecture. The accompanying seminar comprises:<br>• reading scientific publications<br>• preparation of oral presentations |
| **Module Components** | • Lecture: „Light and Matter: Introduction“<br>• Accompanying exercise<br>• Accompanying seminar: journal club<br>• Related examination |
| **Components to be offered in the Current Semester** | **150420** Lecture<br>Light and Matter: Introduction - 2 Hours per Term<br>**150421** Exercise<br>Light and Matter: Introduction - 2 Hours per Term |

**150422** Seminar
Journal Club Light and Matter: Introduction - 2 Hours per Term
**150423** Examination
Light and Matter: Introduction

# Module 13025 Light and Matter: Interaction in Nanostructures

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13025 | Compulsory elective |

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|---|---|
| **Modul Title** | **Light and Matter: Interaction in Nanostructures**<br>Licht und Materie: Wechselwirkung in Nanostrukturen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Fischer, Inga Anita |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are acquainted with the fundamentals of light-matter interaction in nanostructured semiconductors and metals and have gained insight into current research topics. They not only know how to acquire scientific knowledge but are also able to place physical phenomena into a more general context while exploring links between the different topics. In addition, students have acquired personal skills such as the capability for teamwork, precise reasoning, perseverance and openmindedness. |
| **Contents** | • Introduction to the interaction of light and matter: Dielectric functions<br>• Coating systems<br>• Semiconductor Bloch equations<br>• Absorption spectra of semiconductor nanostructures<br>• Plasmons<br>• Photonic crystals and metamaterials<br>• Semiconductor quantum dots |
| **Recommended Prerequisites** | • Sound knowledge of physics at bachelor level |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 90 hours |

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| **Teaching Materials and Literature** | Will be announced during the first lecture: textbooks, scientific publications. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Calculate exercise tasks on at least two exercise dates<br><br>**Final module examination:**<br>• Written examination, 90 min.<br><br>alternatively, depending on the number of student attendees, and by arrangement:<br>• an oral examination, 30-45 min. **OR**<br>• a presentation, 30-45 min.<br><br>are possible.<br><br>The choice of form (written , oral exam or presentation) will be announced in the first lecture. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self-study comprisse:<br>• revising the lectures<br>• reading of scientific publications<br>• preparation of oral presentations |
| **Module Components** | • Lecture: „Light and Matter: Interaction in Nanostructures“<br>• Accompanying exercise<br>• Accompanying laboratory<br>• Related examination |
| **Components to be offered in the Current Semester** | **150424** Examination<br>Light and Matter: Interaction in Nanostructures |

# Module 13038 Nanoelectronics

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13038 | Compulsory elective |

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|---|---|
| **Modul Title** | **Nanoelectronics**<br>Nanoelektronik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students master the basics of nanoelectronics especially methods of acquiring knowledge as well as their exemplified application. Furthermore, social skills of the students as accuracy, perseverance, curiosity, own initiative etc. have been promoted. |
| **Contents** | We discuss the physics of the most important nanoelectronic devices:<br>• resonant tunneling diode<br>• nano-FET (nano field-effect transistor)<br>• laser diode<br><br>For each of these devices a basic quantum mechanical description is derived. Subsequently the numerical evaluation of the theory is demonstrated. In the exercices the student learns to apply existing software solutions. The calculated characteristics will be compared with experimental results. In a more detailed treatment elements of advanced quantum mechanics are introduced. These are the application of Greens functions or Fermi's golden rule. |
| **Recommended Prerequisites** | Knowledge of basic quantum mechanics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | • Supriyo Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br><br>Self-contained studies comprise:<br>• reworking of the lecture<br>• reading of scietific literature<br>• solving of exercises |
| **Module Components** | • Lecture: Nanoelectronics<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13052 Nanocatalysis - Fundamentals and Applications

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13052 | Compulsory elective |

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|---|---|
| **Modul Title** | **Nanocatalysis - Fundamentals and Applications**<br>Nanokatalyse - Grundlagen und Anwendungen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Flege, Jan Ingo |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, the students have a sound understanding of the basic concepts and the essential experimental techniques of heterogeneous nanocatalysis. Building on the topics of this module, they master methods for gaining knowledge, the classification of physical findings in the overall context and the networking of individual results.<br>In addition, the students can use social competences such as the ability to cooperate as well as further individual competences such as accuracy, patience, curiosity, initiative, etc. of the students. |
| **Contents** | • Heterogeneous catalysis: history and fundamentals<br>• Kinetics and elementary steps<br>• Testing of catalysts<br>• In-situ and operando characterization of real and model catalysts<br>• Computational catalysis<br>• Reaction and process engineering<br>• Industrial and renewable energy applications<br>• Photo- and electrocatalysis<br>• Novel trends in nanocatalysis |
| **Recommended Prerequisites** | • Knowledge of solid state physics and chemistry based on a Bachelor study course in physics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester |

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| | Seminar - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • Norskov, J.K., Studt, F., Abild-Petersen, F., Bligaard, T.: Fundamental Concepts in Heterogeneous Catalysis, ,Wiley-VCH, 2014<br>• Kisch, H. Semiconductor Photocatalysis: Principles and Applications, 1st Ed., Wiley-VCH, 2015<br>• Van de Krol, R., Grätzel, M.: Photoelectrochemcial Hydrogen Production, 1st Ed., Springer, 20125<br>• Hamann, C. H., Hamnett, A., Vielstich, W.: Electrochemistry, Wiley-VCH, 2007<br>• Chorkendorff, J.W. Niemantsverdriet: Concepts of Modern Catalysis and Kinetics, Wiley-VCH, Weinheim 2007<br>• R.A. van Santen, M. Neurock: Molecular Heterogeneous Catalysis. Wiley-VCH, Weinheim 2006<br>• J.M. Thomas, W.J. Thomas: Principles and Practice of Heterogeneous Catalysis, Wiley-VCH, 2007 |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br><br>Self-organized studies comprise:<br>• Analysis and evaluation of the lectures<br>• Planning of exercise tasks |
| **Module Components** | • Lecture: Nanocatalysis - Fundamentals and Applications<br>• Accompanying exercise<br>• Block Seminar<br>• Related examination |
| **Components to be offered in the Current Semester** | **150310** Lecture<br>Nanocatalysis - Fundamentals and Applications - 4 Hours per Term<br>**150311** Exercise<br>Nanocatalysis - Fundamentals and Applications - 2 Hours per Term<br>**150312** Examination<br>Nanocatalysis - Fundamentals and Applications |

# Module 13752 Advanced Micro Systems, Focus on Microsensors

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13752 | Compulsory elective |

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|---|---|
| **Modul Title** | **Advanced Micro Systems, Focus on Microsensors**<br>Fortgeschrittene Mikrosystemtechnik, Schwerpunkt auf Mikrosensoren |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr. rer. nat. habil. Schenk, Harald |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the module, students have in-depth knowledge in the field of silicon-based microsystems technology, especially in the area of microsensor technology. They are able to analyze problems in this field and to develop solutions to problems, In addition, social competencies such as the ability to cooperate, as well as other individual competencies such as diligence, perseverance, curiosity, initiative, frustration tolerance, etc. were promoted in the students. |
| **Contents** | • Differentiation of sensors, transducers, actuators<br>• Classification of sensors according to operating principles and intended use<br>• Characteristics of sensors such as linearity, hysteresis, resolution<br>• Analogue and digital sensors From elementary sensors to signal processing<br>• Design, mode of operation and properties of selected capacitive, optical, chemical, acoustic and ultrasonic sensors<br>• Application areas of sensors<br>• Signal conditioning<br>• Current research activities in microsensor technology<br>• Principles and examples of microactuators and microtransducers |
| **Recommended Prerequisites** | • Sound knowledge of solid state physics at or beyond the bachelor level<br>• Knowledge of the topics of module 13019 *Micro Systems* |
| **Mandatory Prerequisites** | none |

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| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 1 hours per week per semester<br>Self organised studies - 135 hours |
| **Teaching Materials and Literature** | • M. Madou, "Fundamentals of Microfabrication„, CRC Press , Boca Raton-NewYork (2002)<br>• Gianchandani, Yogesh B.; Tabata, Osamu; Zappe, Hans P.: „Comprehensive Microsystems“, Vol. 1-3, Elsevier, Amsterdam (2008)<br><br>A detailed bibliography will be provided in the first lecture. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful seminar talk (with written part)<br><br>**Final module examination:**<br>• Written exam, 90 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self-organized studies are composed of:<br>• reworking of lecture<br>• literature work<br>• preparation of a talk |
| **Module Components** | • Lecture: Advanced Micro Systems, Focus on Microsensors<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **152271** Examination<br>Radio Frequency Integrated Circuit Design for Wireless Systems |

# Module 13753 Advanced Laboratory Techniques and Metrology

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13753 | Compulsory elective |

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|---|---|
| **Modul Title** | **Advanced Laboratory Techniques and Metrology**<br>Fortgeschrittene Labor- und Messtechnik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr. rer. nat. habil. Schenk, Harald |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the module, students have in-depth knowledge in the field of silicon-based microsystems technology, especially in the area of microsensor technology. They are able to analyze problems in this field and to develop solutions to problems, In addition, social competencies such as the ability to cooperate, as well as other individual competencies such as diligence, perseverance, curiosity, initiative, frustration tolerance, etc. were promoted in the students. |
| **Contents** | • Types of measurement errors (systematic/random) and how to account for<br>• Analytical consideration of errors and error propagation<br>• Principles, properties and use of<br>- Raman Spectroscopy<br>- Optical Coherence Tomography<br>- Digital Holographic Microscopy<br>- Ultrasound Spectroscopy<br>- X-Ray Diffractometer<br>- Mass Spectroscopy |
| **Recommended Prerequisites** | • Basic knowledge in physics (optics, electromagnetism) and electrical engineering<br>• Knowledge of the topics of module 13020 *Laboratory Techniques and Metrology* |
| **Mandatory Prerequisites** | none |

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| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | List of literature will be presented at first lecture. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful seminar talk (with written handout)<br><br>**Final module examination:**<br>• Oral examination, 30-45 min |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“ |
| **Module Components** | • Lecture: Laboratory Techniques and Metrology<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14031 Physics of Modern Devices

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14031 | Compulsory elective |

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|---|---|
| **Modul Title** | **Physics of Modern Devices**<br>Physik moderner Bauelemente |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Fischer, Inga Anita |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are acquainted with concepts of quantum mechanics and solid state physics and their application to the description of modern devices as well as their relevance for nanoscience, nanotechnology and information technology using real-world examples. They not only know how to acquire scientific knowledge but are also able to place physical phenomena into a more general context while exploring links between the different topics. In addition, students possess personal skills such as the capability for teamwork, precise reasoning, perseverance and openmindedness. |
| **Contents** | • Quantum mechanics - fundamental concepts relevant to the description of modern devices<br>• Solid state physics - fundamental concepts relevant to the description of modern devices<br>• Band structure calculations: Graphene<br>• Effective mass theory and tunneling currents in semiconductor devices<br>• Application examples (Flash memory, tunnel diodes, quantum effects in MOSFETs, ...) |
| **Recommended Prerequisites** | Knowledge of physics at a level corresponding to the first four semesters of a Bachelor’s degree in physics or corresponding to the level of a Bachelor’s degree in electrical engineering. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester |

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| | Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • A. F. J. Levi, Applied Quantum Mechanics<br><br>Will be added during the first lecture: scientific publications. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written exam, 90 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physik B.Sc.: Compulsory elective module in complex „Physikalisches Vertiefungsfach“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Mandatory module for students without a Bachelor's degree in physics<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“ (if no mandatory module) |
| **Module Components** | • Lecture: Physics of Modern Devices<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **152260** Lecture<br>Physics of Modern Devices - 2 Hours per Term<br>**152261** Exercise<br>Physics of Modern Devices - 2 Hours per Term<br>**152262** Examination<br>Physics of Modern Devices |

# Module 14490 Advanced Laboratory Techniques and Metrology

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14490 | Compulsory elective |

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|---|---|
| **Modul Title** | **Advanced Laboratory Techniques and Metrology**<br>Fortgeschrittene Labor- und Messtechnik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr. rer. nat. habil. Schenk, Harald |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | Upon successful completion of the module, students will have a thorough and organized understanding of advanced techniques for characterizing nanostructures, ultrathin films, and nanocomposites, as well as their essential role in modern micro/nano systems and semiconductor devices. They can recognize how the performance, functionality, and reliability of these devices are closely tied to the quality of these components. |
| **Contents** | • Fundamentals and importance of various advance measurement techniques<br>• Principles, properties and Application of e.g.<br>  • X-Ray Diffractometer<br>  • Raman Spectroscopy<br>  • Optical Coherence Tomography<br>  • Ultrasound Spectroscopy<br>  • Mass Spectroscopy |
| **Recommended Prerequisites** | • Basic knowledge in physics (optics, electromagnetism) and electrical engineering<br>• Knowledge of the topics of module 13020 Laboratory Techniques and Metrology |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 1 hours per week per semester |

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| | Self organised studies - 135 hours |
| **Teaching Materials and Literature** | • Suryanarayana, C., et al., *X-ray diffraction: A practical approach, Springer New York, NY* (1998).<br>• Ferraro, John R. *Introductory raman spectroscopy*. Elsevier, 2003.<br>• Schneider, Simon. *Optical coherence tomography for characterization of nanocomposite materials*. KIT Scientific Publishing, 2021.<br>• Gericke, OTTO R. "Ultrasonic spectroscopy." *Nondestructive Evaluation of Materials*. Boston, MA: Springer US, 1979. 299-320.<br>• Watson, J. Throck, and O. David Sparkman. *Introduction to mass spectrometry: instrumentation, applications, and strategies for data interpretation*. John Wiley & Sons, 2007. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • seminar talk, 20 minutes, with written part, 10 pages (50%)<br>• written exam, 75 minutes (50%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 10 |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Nanophysics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“ |
| **Module Components** | • Lecture: Advanced Laboratory Techniques and Metrology<br>• Accompanying seminar<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 15015 Interfacial Engineering and 2D Semiconductors for Post Moore Nanoelectronics

assign to: Nanophysics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 15015 | Compulsory elective |

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|---|---|
| **Modul Title** | **Interfacial Engineering and 2D Semiconductors for Post Moore Nanoelectronics**<br>Grenzflächen-Engineering und 2D-Halbleiter für die Post-Moore Nanoelektronik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Flege, Jan Ingo |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Upon successful completion of the module, students understand the principles of interfacial band engineering central to modern micro– and nanoelectronics. They are able to construct and analyze band diagrams across a wide range of material systems and interfaces, and relate band alignment to the operation of fundamental electronic building blocks. Students can apply these concepts to diverse thin–film and 2D semiconductor heterostructures, gaining insight into interface functionality and pathways for device optimization. |
| **Contents** | • A brief introduction to solid–state physics: Hall experiment and holes as carriers, Bloch's theorem, Kronig-Penney model, k–space concept, E(k) relation, parabolic approximation, effective mass, doping in semiconductors.<br>• p-n junction as the simplest example of the band alignment and the rules on how to construct interfacial band diagrams<br>• metal-SC junction, Shottky contacts, Fermi level pinning, MIGs, mirror charges<br>• semiconductor-insulator interface, interfacial charge traps, interfacial dipoles, Coulomb drag<br>• A brief overview of the MOS capacitor from the perspective of the band diagrams, planar MOSFETs and modern non-planar MOS-FET geometries in Si-based electronics.<br>• Memory elements: Charge–trap memory, DRAM, SRAM, CCDs vs CMOS detectors |

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| | • Brief introduction to deep learning and the challenges for von Neuman-based architectures<br>• Beyond von Neuman architectures NPUs, MPUs, VMMPs, and the concept of neuromorphic electronics<br>• Neuromorphic elements: memory transistors, FeRAM, FeFETs, NPUs, MPUs, VMMPs<br>• 2D electron gas in electronics: III–V semiconductors, HEMTs, TDs, RTDs<br>• In brief IV-IV semiconductor interfaces and the prospects of solid-state quantum computing<br>• Magnetism in solid-state devices: MTJs and SST–MRAMs<br>• 2D materials–based electronics |
| **Recommended Prerequisites** | Sound knowledge of solid-state physics, enthusiasm for microelectronics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • Lecture notes provided prior to the lectures<br>• list of the literature (selected works):<br><br>• Yu & Cardona — Fundamentals of Semiconductors<br>• Sze & Ng — Physics of Semiconductor Devices<br>• Waser — Nanoelectronics and Information Technology |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral exam, 45 min or<br>• presentation on given topic that goes beyond the course, 15 min + 30 min questions<br><br>Students may choose between the two exam options. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices"<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus”, topic area „Nanophysics" |
| **Module Components** | • Lecture Interfacial Engineering and 2D Semiconductors for Post Moore Nanoelectronics |
| **Components to be offered in the Current Semester** | **150350** Lecture<br>Interfacial Engineering and 2D Semiconductors for Post Moore Nanoelectronics - 2 Hours per Term |

# Module 11763 Crystal Growth

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11763 | Compulsory elective |

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|---|---|
| **Modul Title** | **Crystal Growth**<br>Kristallzüchtung |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have a good grasp of the fundamentals and methods for the preparation of bulk crystals, crystalline layers, and nano-structures, the basics of defects in crystals as well as applications of different crystalline materials. They are able to familiarize themselves with a technical topic independently.<br>Additionally, students have improved presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | The following topics serve as examples to illustrate the connection between basic and applied sciences and to demonstrate the methods of attaining new perceptions:<br>• Basics (theory of nucleation, morphological stability, interface kinetics, atomistic models)·<br>• Thermodynamic approach<br>• Hydrodynamic concepts for growth processes<br>• Growth methods for single crystals, epitaxial layers and nano-structures<br>• Defects in real crystals<br>• Applications of single crystalline materials with emphasis on semiconductors for solid state and opto-electronics<br><br>A visit of the Institute for Crystal Growth in Berlin-Adlershof is also planned at the end of the course. |
| **Recommended Prerequisites** | Knowledge in solid state physics on the level of a Bachelor course in Physics. |

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| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • W. Kleber, An Introduction to Crystallography, 17th edition, VEB Verlag Technik Berlin, First English edition 1970<br>• I.V. Markov. Crystal Growth for Beginners – Fundamentals of Nucleation, Crystal Growth and Epitaxy, World Scientific, Singapore 1995<br>• F. A. Kröger, The Chemistry of Imperfect Crystals (North-Holland, Amsterdam 1974)<br>• N. A. Gokcen, R.G. Reddy, Thermodynamics, Second Edition, Plenum Press, New York 1996<br>• ed. D. T. J. Hurle, Handbook of Crystal Growth, North Holland, 1994, Vol. 1a,b and 2a |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful presentation of seminar paper<br><br>**Final module examination:**<br>• Written examination, 90 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“<br><br>Self organised studies:<br>• re-work of the lecture<br>• means of English literature<br>• preparation of a short talk<br><br>A visit of the Institute for Crystal Growth in Berlin-Adlershof is also planned at the end of the course. |
| **Module Components** | • Lecture: Crystal Growth<br>• Accompanying exercises<br>• Related exam |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13016 Characterization of Micro- and Nanomaterials

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13016 | Compulsory elective |

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|---|---|
| **Modul Title** | **Characterization of Micro- and Nanomaterials**<br>Charakterisierung von Mikro- und Nanomaterialien |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Flege, Jan Ingo |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have caught a good grasp of experimental methods for the characterization of micro- and nanomaterials. They are able to familiarize themselves with a technical topic independently.<br>Additionally, students have continually improved presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | The following topics serve as examples to illustrate the connection between basic and applied sciences and to demonstrate the methods of attaining new perceptions:<br>• internal stress and x-ray diffractometry,<br>• elastic waves and elastic properties,<br>• deformation analysis in the micro and nano regime,<br>• Scanning probe microscopy,<br>• focused ion beam,<br>• nanoindenters,<br>• thermography and thermal investigation of electrical micro-devices,<br>• Laser techniques,<br>• simulations for reliability testing,<br>• compound materials |
| **Recommended Prerequisites** | • Sound knowledge of physics at or beyond the bachelor level. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | • Will be offered during the first lecture. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 120 min. **OR**<br><br>With small number of participants it is also possible to organize the assessment mode as:<br>• Oral examination, 30-45 min. **OR**<br>• Presentation, 30-45 min.<br><br>In the first lecture it will be announced, if the examination will be offered as written exam, oral exam or presentation. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self organized studies comprise:<br>• reworking of the lecture,<br>• reading of original papers (in English). |
| **Module Components** | • Lecture: Characterizatin of Micro- and Nanomaterials<br>• Related exam |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13021 Surface Physics and 2D Materials

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13021 | Compulsory elective |

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|---|---|
| **Modul Title** | **Surface Physics and 2D Materials**<br>Oberflächenphysik und 2D-Materialien |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Flege, Jan Ingo |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the module, the students master the basics of experimental and theoretical concepts of surface physics. Using the example of the topic of this module, they know methods for gaining knowledge, classify physical findings in the overall context and cross link the individual results.<br>In addition, they can apply social competences such as the ability to cooperate as well as other individual competences such as accuracy, patience, curiosity, initiative, etc. |
| **Contents** | • Morphology and structure of surfaces<br>• Thermodynamics of surfaces<br>• Adsorption and diffusion on surfaces<br>• Nucleation and growth<br>• Electronic properties of surfaces<br>• Optical and magnetic properties of surfaces<br>• Chemical reactions on surfaces<br>• Production of two-dimensional materials<br>• Structural properties of two-dimensional materials<br>• Electronic properties of two-dimensional materials |
| **Recommended Prerequisites** | • Knowledge of solid state physics and chemistry based on a Bachelor study course in physics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester |

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| | Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • H. Ibach – Physics of Surfaces and Interfaces<br>• H. Lüth – Solid Surfaces, Interfaces and Thin Films<br>• K. Kolasinski – Surface Science<br>• A. Zangwill – Physics at Surfaces |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“<br><br>Self organised studies comprise:<br>• analysis and evaluation of the lectures<br>• preparation of short reports<br>• planning of exercise tasks |
| **Module Components** | • Lecture: Surface Physics and 2D Materials<br>• Accompanying exercises<br>• Related Examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14295 Semiconductor Physics for Applied Quantum Structures

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14295 | Compulsory elective |

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|---|---|
| **Modul Title** | **Semiconductor Physics for Applied Quantum Structures**<br>Halbleiterphysik für angewandte Quantenstrukturen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wenger, Christian |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students can handle the basics of experimental solid state physics concerning theoretical and methodical aspects. In particular, they will be proficient in spectroscopic methods.They are able to bridge the theoretical and experimental aspects of spectroscopic methods in solid state physics to provide an appropriate framework for the interpretation and modeling of experimental results. Thus, they are able to grasp new frontiers in the development of innovative applications.<br>Based on the topics of this module, they know methods for gaining knowledge, the classify physical findings into the overall context and the cross link individual outcomes. Furthermore, they can apply their social competences like cooperation skills as well as other individual competences like accuracy, patience, curiosity, their own initiative. |
| **Contents** | • Foundation for Quantum Devices: Understanding the critical role of semiconductors in quantum device environments.<br>• Heterostructure Growth and Characterization: Techniques for fabricating and characterizing high-quality quantum structures like quantum dots and wells.<br>• Band Theory and Quantum Mechanics: Theoretical frameworks, including tight binding and k#p methods, for designing and analyzing quantum materials.<br>• Mechanical and Electrical Properties: Exploring the impact of mechanical properties on band structure and optimizing electrical and transport properties for qubit performance. |

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| | • Semiconductor Devices as Building Blocks: Basics of semiconductor devices such as transistors and diodes, essential for complex quantum devices.<br>• Quantum Processes: Mastering processes like entanglement and superposition, crucial for quantum computing and communication.<br>• Tunnel Devices and Qubits: Principles and practical aspects of devices exploiting quantum tunneling and qubits, fundamental to quantum computers.<br>• Hands-on Learning: Practical sessions focused on reading research papers and identifying key insights, visit to IHP labs. |
| **Recommended Prerequisites** | • Knowledge of solid state physics and chemistry based on a Bachelor study course in physics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • G. Grosso and G. Pastori Parravicini *Solid State Physics*, Academic Press (2014)<br>• C. Kittel *Introduction to Solid State Physics*, Wiley (2004)<br>• P. Yu, M. Cardona *Fundamentals of Semiconductors*, Springer (2010)<br>• Sze, S.M. *Physics of Semiconductor Devices,* Wiley (2021) |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“<br>• Study programme Micro- and Nanoelectronisc M.Sc.: Compulsory elective module in complex „Technology and Devices“ |
| **Module Components** | • Lecture: Semiconductor Physics for Applied Quantum Structures<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | **152110** Lecture<br>Semiconductor Physics for Applied Quantum Structures - 2 Hours per Term<br>**152111** Exercise<br>Semiconductor Physics for Applied Quantum Structures - 2 Hours per Term<br>**152112** Examination<br>Semiconductor Physics for Applied Quantum Structures |

# Module 14846 Principles of Superconductivity

assign to: Condensed Matter Physics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14846 | Compulsory elective |

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|---|---|
| **Modul Title** | **Principles of Superconductivity**<br>Grundlagen der Supraleitung |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have acquired basic knowledge in the physics of superconductivity with regard to theoretical and phenomenological aspects. They understand the connection between basic and applied science and know methods of attaining new perceptions. Additionally the module supports presentation skills and further competences as accurateness, endurance and curiosity. |
| **Contents** | • Experimental and theoretical foundations of superconductivity, phenomenological description: London and Ginzburg-Landau theories, Superconductors in a magnetic field, Josephson effects.<br>• Microscopic description: pairing mechanism, Cooper problem, BCS theory, tunneling effects.<br>• New developments: high Tc superconductivity. |
| **Recommended Prerequisites** | • Knowledge of solid state physics and theoretical physics at bachelor level. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • W. Buckel, R. Kleiner: Superconductivity: Fundamentals and Applications<br>• M. Thinkam, Introduction to Superconductivity, Krieger Publishing<br>• D. Gennes, Superconductivity of Metals and Alloys, Addison Wesley |

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| | • J. R. Shrieffer, Theory of Superconductivity, Addison Wesley |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments<br><br>**Final module examination:**<br>• Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in the complexes „Physical Specialization with Theoretical Focus“ and „Physical Specialization with Experimental Focus“, topic area „Condensed Matter Physics“ |
| **Module Components** | • Lecture: Principles of Superconductivity<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13015 Particle and Astroparticle Physics

assign to: Theory, Simulation and Further Topics

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13015 | Compulsory elective |

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|---|---|
| **Modul Title** | **Particle and Astroparticle Physics**<br>Teilchen- und Astroteilchenphysik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Lohmann, Wolfgang |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module students will have acquired a profound knowledge about modern concepts of electromagnetic, weak and strong interactions in sub-nuclear, particle and astroparticle physics and modern experimental techniques used in the field. They know about the cognitive methods used in fundamental research, and their application in example-experiments.<br>Creativity, initiative and teamwork, prerequisites for successful research work, have been developed. |
| **Contents** | The lectures cover:<br>• structure of nuclei, radioactivity, nuclear fission and fusion, energy production in stars<br>• modern concepts of particle and astroparticle physics<br>• fundamental particles and fields, parity and CP violation<br>• cosmic rays, dark matter and the development of the universe<br>• experimenal methods, detector technologies, key experiments<br><br>A visit of DESY Hamburg (Research Center of Helmholtz Association) is planned. |
| **Recommended Prerequisites** | Knowledge of experimental physics, e.g. modules<br>• 11865: Allgemeine Physik I (Mechanik, Thermodynamik)<br>• 11866: Allgemeine Physik II (Elektrizität und Magnetismus)<br>• 11867: Allgemeine Physik III (Optik, Atome und Moleküle)<br>• 11868: Allgemeine Physik IV (Festkörperphysik),<br><br>as well as basics in quantum mechanics, e.g. module |

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| | • 11874: Theoretische Physik G1 (Mechanik, Quantenmechanik) |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | Will be announced during the first lecture. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physik B.Sc.: Compulsory elective module in complex „Physikalisches Vertiefungsfach“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Physical Specialization with Experimental Focus“, topic area „Theory, Simulation and further topics“ |
| **Module Components** | • Lecture: "Partical and Astroparticle Physics"<br>• Related exam |
| **Components to be offered in the Current Semester** | No assignment |

# Module 11221 Fundamentals in Power Electronics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11221 | Compulsory elective |

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|---|---|
| **Modul Title** | **Fundamentals in Power Electronics**<br>Grundlagen der Leistungselektronik |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Möhlenkamp, Georg |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Students learn to understand the functional principle of power electronics, their specific components, control structures and the characteristic behaviour. They are able to find suitable concepts and define components and auxiliaries for power converters. |
| **Contents** | • Definition of power electronics<br>• Components and their static and transient behaviour<br>• Circuit topologies as grid commutated converter<br>• Self commutated converter<br>• Dc-dc-converter<br>• Resonant and quasi-resonant converter<br>• Single and three phase applications<br>• Characteristic values of components and topologies<br>• Cooling<br>• Passive components and filters<br>• Firing<br>• Driver and protection devices<br>• Pulse-width-modulation<br>• Simulation tools |
| **Recommended Prerequisites** | Fundamentals in electrical engineering |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 1 hours per week per semester<br>Practical training - 1 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | will be given in lecture |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of the laboratory work<br><br>**Final Module Examination:**<br>• Written examination, 90 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | The seminar contains a mixture of exercises, laboratory tests and homework. |
| **Module Components** | • Fundamenatls in Power Electronics (lecture/seminar/laboratory) |
| **Components to be offered in the Current Semester** | **320552** Practical training<br>Fundamentals in Power Electronics - 1 Hours per Term<br>**320551** Lecture/Seminar<br>Fundamentals in Power Electronics - 3 Hours per Term<br>**320576** Examination<br>Fundamentals in Power Electronics |

# Module 11847 Neural Networks and Learning Theory

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11847 | Compulsory elective |

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|---|---|
| **Modul Title** | **Neural Networks and Learning Theory**<br>Neuronale Netze und Lerntheorie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil Meer, Klaus |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Each summer semester even year |
| **Credits** | 8 |
| **Learning Outcome** | Students will get insight into different network architectures and their principles of operation. Notions like artificial intelligence and automatic learning will be made precise during the course. A central issue is the understanding of mathematical ideas underlying different network learning algorithms. This includes both positive solutions of problems and knowledge about limits of the approaches studied. |
| **Contents** | Some central network architectures are treated. These architectures differ in the way they manipulate input data, the way they perform learning tasks and the analysis of corresponding algorithms by mathematical means. More precisely, the following types of networks are covered:<br>• General aspects of architecures, in particular feedforward nets, recurrent nets<br>• Perceptron network, perceptron learning algorithm<br>• Backpropagation algorithm<br>• Radial basis function networks<br>• Support Vector Machines<br>• Learning theory and Vapnik-Chervonenkis dimension<br>• Self-organizing networks<br>• Hopfield networks<br><br>Special emphasis will be given to the mathematical analysis of algorithms. This will make it necessary to study some basic facts of optimization and probability theory. |

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| **Recommended Prerequisites** | Basic knowledge both concerning optimality criteria in differentiable optimization and probability theory are advisable, but will be treated briefly in the course.<br>Solid knowledge of the content of module<br>• 11213: Mathematik IT -3 (Analysis) |
| **Mandatory Prerequisites** | No successful participation in associated phase-out module 12450 *Neuronale Netze und Lerntheorie*. |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • E. Alpaydin: Maschinelles Lernen, Oldenbourg Verlag München, 2008<br>• M. Anthony, N.Biggs: Computational Learning Theory, Cambridge University Press 1997<br>• N. Christiani, J. Shawe-Taylor: An Introduction to Support Vector Machines and kernel-based Learning Methods, Cambridge Univ. Press, 2003<br>• A.C.C Coolen, R. Kühn, P. Sollich: Theory of Neural Information Processing Systems, Oxford University Press 2005<br>• P. Fischer: Algorithmisches Lernen, Teubner 1999<br>• P. Flach: Machine Learning: The Art and Science of Algorithms that Make Sense of Data, Cambridge University Press 2012<br>• F. M. Ham, I. Kostanic: Principles of Neurocomputing for Science & Engineering, McGraw Hill 2001<br>• S. Haykin: Neural Networks, Prentice Hall, 1999<br>• R. Rojas: Theorie der neuronalen Netze, Springer 1996<br>• S. Shalev-Shwartz, S. Ben-David: Understanding Machine Learning, Cambridge University Press 2014. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of homework (fortnightly) and/or successful completion of tests (approx. 4 tests of 15-30 minutes each, written during the lecture period)<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30-45 min. (with small number of participants)<br><br>In the first lecture it will be announced, if the examination will be offered in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 100 |
| **Remarks** | • Study programme Informatik M.Sc.: Compulsory elective module in complex „Grundlagen der Informatik" (level 400)<br>• Study programme Cyber Security M.Sc.: Compulsory elective module in complex „Computer Science" |

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| | • Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Learning and Reasoning“<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Kognitions- und Neurowissenschaft“<br>• Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Kombinatorik“<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Advanced Mathematical Methods in Data Science“ |
| **Module Components** | • Lecture: Neural Networks and Learning Theory<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **120162** Examination<br>Neural Networks and Learning Theory (Wiederholung) |

# Module 11859 Cryptography

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11859 | Compulsory elective |

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|---|---|
| **Modul Title** | **Cryptography**<br>Kryptographie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil Meer, Klaus<br>Prof. Dr. rer. nat. Averkov, Gennadiy |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 8 |
| **Learning Outcome** | The students should<br>• know relevant symmetric and asymmetric crypto systems<br>• understand the mathematics relevant for desgining and analyzing crypto systems<br>• be able to explain and use the most important approaches to cryptography<br>• gain the ability to understand state-of-the-art scientific work in the area of cryptography |
| **Contents** | • Mathematical Foundations relevant in the context of cryptography, including basic number theory, finite fields, polynomial rings, factorization<br>• elementary crypto systems<br>• Symmetric Cryptosystems DES and AES<br>• public key cryptography, RSA - discrete logarithm, elliptic curve systems<br>• secure signature and authentication methods<br>• security of crypto systems<br>• zero knowledge proofs<br>• complexity theoretic aspects |
| **Recommended Prerequisites** | Basic knowledge about discrete mathematics and linear algebra, for example as covered by the modules<br>• 11101: Lineare Algebra und analytische Geometrie I<br>• 11102: Lineare Algebra und analytische Geometrie II |

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| | or<br>• 11112: Mathematik IT-1 (Diskrete Mathematik)<br>• 11113: Mathematik IT-2 (Lineare Algebra) |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | **Books in English**<br>• G. Baumslag, B. Fine, M. Kreuzer, G. Rosenberger: A Course in Mathematical Cryptography, De Gruyter, 2015<br>• J. Hoffstein, J. Pipher, J.H. Silverman: An Introduction to Mathematical Cryptography, 2nd Edition, Springer 2014.<br>• D.R. Stinson: Cryptography: Theory and Practice, CRC, 1995<br><br>**Books in German**<br>• V. Diekert, M. Kufleitner, G. Rosenberger: Diskrete Algebraische Methoden, De Gruyter 2013 |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of homework (fortnightly) and/or successful completion of tests (approx. 4 tests of 15-30 minutes each, written during the lecture period)<br><br>**Final module examination:**<br>• Written examination, 90 minutes, **OR**<br>• Oral examination, 30 - 45 minutes, (in case of a small number of participants)<br><br>In the first lecture it will be anounced, if the examination will be offered in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 80 |
| **Remarks** | • Study programme Cyber Security M.Sc.: Mandatory module in complex „Cyber Security Basics“<br>• Study programme Informatik M.Sc.: Compulsory elective module in complex „Mathematik“ or in field of application „Mathematik“<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Advanced Methods“<br>• Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Kombinatorik“<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Physics M. Sc.: Compulsory elective module in complex „Minor Subject" |

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| | • Study programme Mathematics M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Combinatorics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Fundamentals of Data Science“ |
| **Module Components** | • Lecture: Cryptography<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | **120164** Examination<br>Cryptography (Wiederholung) |

# Module 11864 Wireless Sensor Networks: Concepts, Protocols and Applications

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 11864 | Compulsory elective |

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|---|---|
| **Modul Title** | **Wireless Sensor Networks: Concepts, Protocols and Applications**<br>Drahtlose Sensornetze: Konzepte, Protokolle und Anwendungen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Piotrowski, Krzysztof |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Participants know the architecture of wireless sensor networks. They can select and classify protocols for different applications. Participants can design and understand complex protocols. They understand the connection between physical impacts on communication and necessary technical means to keep the network alive. They can design own networks and argue about the design decisions. They can judge about future developments. |
| **Contents** | Architecture of sensor networks, node-architectures, MAC protocols, addressing, routing, synchronisation, operating systems, topology management, applications, security and key-exchange protocols. |
| **Recommended Prerequisites** | Basic knowledge of technical computer science concepts and communication systems. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Holger Karl, Andreas Willig, Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons, 2007<br>• Jochen H. Schiller, Mobile Communications, Second Edition, Addison-Wesley, 2003 |

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| | More might be announced during the first class meeting. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise assignments<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30 min. (with small number of participants)<br><br>In the first lecture it will be anounced, if the examination will be offered in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Informatik B.Sc.: Compulsory elective module in complex "Angewandte und Technische Informatik" (level 300)<br>• Study programme Cyber Security M.Sc.: Compulsory elective module in complex "Computer Science"<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Software-basierte Systeme“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Applications“ |
| **Module Components** | • Lecture/Exercise: Wireless Sensornetworks: Concepts, Protocolls and Applications<br>• Related examination |
| **Components to be offered in the Current Semester** | **122130** Lecture/Exercise<br>Wireless Sensor Networks: Concepts, Protocolls and Applications - 4 Hours per Term<br>**122131** Examination<br>Wireless Sensor Networks: Concepts, Protocolls and Applications |

# Module 12165 Renewable Energy Technologies for Power Supply

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 12165 | Compulsory elective |

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|---|---|
| **Modul Title** | **Renewable Energy Technologies for Power Supply**<br>Energieerzeugung auf Basis erneuerbarer Energien |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Röntzsch, Lars |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | The participants of the module acquire advanced knowledge in the design, operation, and application of renewable energy systems, including solar energy (solar thermal and photovoltaics), wind energy, hydroelectric power, geothermal energy (both near-surface and deep), biomass, and energy storage technologies, with a focus on hydrogen technology. They can analyze and reflect on the interactions between these subfields, considering their technical and ecological implications, and are capable of making scientifically grounded judgments within the discipline. The participants of the module develop the ability to formulate their own research questions and address them using appropriate scientific methods. They can effectively engage in domain-specific and interdisciplinary discussions, presenting complex topics clearly and persuasively to diverse audiences. Additionally, they demonstrate the ability to independently acquire new knowledge and apply it to solve and critically evaluate application- or research-oriented challenges. |
| **Contents** | Design, operation and use of:<br>• Solar energy (photovoltaics, solar thermal)<br>• Wind energy<br>• Geothermal energy (deep and near-surface)<br>• Biomass<br>• Hydroelectric power<br>• Energy storage inclusive hydrogen technology |
| **Recommended Prerequisites** | <section class="text-token-text-primary w- |

full focus:outline-none has-data-writing-block:pointer-events-none [&:has([data-writing-block])>*]:pointer-events-auto R6Vx5W_threadScrollVars scroll-mb-[calc(var(--scroll-root-safe-area-inset-bottom,0px)+var(--thread-response-height))] scroll-mt-[calc(var(--header-height)+min(200px,max(70px,20svh)))]" dir="auto" data-turn-id="request-WEB:a3431c09-7954-4939-889f-9a2bd9d2dbf2-3" data-turn-id-container="request-WEB:a3431c09-7954-4939-889f-9a2bd9d2dbf2-3" data-testid="conversation-turn-6" data-scroll-anchor="false" data-turn="assistant"><div class="text-base my-auto mx-auto pb-10 [--thread-content-margin:var(--thread-content-margin-xs,calc(var(--spacing)*4))] @w-sm/main:[--thread-content-margin:var(--thread-content-margin-sm,calc(var(--spacing)*6))] @w-lg/main:[--thread-content-margin:var(--thread-content-margin-lg,calc(var(--spacing)*16))] px-(--thread-content-margin)"><div class="[--thread-content-max-width:40rem] @w-lg/main:[--thread-content-max-width:48rem] mx-auto max-w-(--thread-content-max-width) flex-1 group/turn-messages focus-visible:outline-hidden relative flex w-full min-w-0 flex-col agent-turn"> <div class="min-h-8 text-message relative flex w-full flex-col items-end gap-2 text-start break-words whitespace-normal outline-none keyboard-focused:focus-ring [.text-message +&]:mt-1" dir="auto" tabindex="0" data-message-author-role="assistant" data-message-id="c4da9da5-dfdc-4888-9d7e-9396a38a3b90" data-message-model-slug="gpt-5-5" data-turn-start-message="true"> <p data-start="391" data-end="691" data-is-last-node="" data-is-only-node="">Completed Bachelor’s degree in a relevant field such as natural sciences, engineering, environmental engineering, energy engineering, process engineering, or a comparable degree programme. Very good knowledge and a solid understanding of engineering, physics, chemistry, and mathematics are required. </section>

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| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | The course documents are provided in the learning management system Moodle. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Final written exam (120 min) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 60 |
| **Remarks** | none |
| **Module Components** | Lectures, exam |

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| **Components to be offered in the Current Semester** | **320461** Lecture<br>Renewable Energy Technologies for Power Supply - 4 Hours per Term<br>**320483** Examination<br>Renewable Energy Technologies for Power Supply |

# Module 12233 Experiments in Aerodynamics and Fluid Mechanics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 12233 | Compulsory elective |

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|---|---|
| **Modul Title** | **Experiments in Aerodynamics and Fluid Mechanics**<br>Experimente in Aerodynamik und Strömungslehre |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Egbers, Christoph |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Participants of the module Experiments in aerodynamics and fluid mechanics will be able to understand the topic from an analytic and a practical point of view. The main scope is the understanding of fundamental Fluid mechanics. At the end of the module the students are able to understand basic aerodynamic and fluid mechanics phenomena as well as measurement techniques which are state of the art. |
| **Contents** | The specific topics will be explained theoretically in the lecture while in the exercise experiments will be performed.<br>The experiments will focus on different fundamental flow phenomena and investigate them using different measurement techniques. The main contents of the module will be:<br>• Wind tunnel<br>• Water tunnel<br>• Flow around bodys<br>• Principle of Airfoil<br>• Laminar flow<br>• Turbulence<br>• Pipe flow<br>• Rotating Machinery<br>• Flow Instabilities<br>• Taylor-Couette flow<br>• Convection<br>• Aeroacoustics<br>• Aeolsharp<br>• Karman Vortex street<br>• Car Aerodynamics<br>• Wheel housing |

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| | • Flow Visualization techniques<br>• Pressure measurements<br>• LASER-based measurement techniques<br>• Particle Image Velocimetry<br>• Laser Doppler Anemometry |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 1 hours per week per semester<br>Exercise - 3 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Selected literature will be presented at the beginning of the module.<br>• Guidelines for the experiments will be given in first lecture |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Written project reports of 10 experiments (2/3)<br>• Oral defense of one experiment, 10 minutes (1/3) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | This module is based on experimental and fluid mechanical knowledge. The interested students should bring skills on these fields. |
| **Module Components** | participation in lecture, exercise |
| **Components to be offered in the Current Semester** | **350124** Lecture<br>Experiments in Aerodynamics and fluid mechanics - 1 Hours per Term<br>**350125** Exercise<br>Experiments in Aerodynamics and fluid mechanics - 3 Hours per Term |

# Module 12826 Mathematical Data Science

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 12826 | Compulsory elective |

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|---|---|
| **Modul Title** | **Mathematical Data Science**<br>Mathematische Grundlagen der Data Science |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Hartmann, Carsten |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 8 |
| **Learning Outcome** | After successfully completing the module, students have deepened their knowledge of stochastics acquired in the basic modules. They know the mathematical and statistical methods from data analysis. They have acquired basic skills for in-depth modules in stochastics or optimization. They have gained experience in doing independent research. |
| **Contents** | Choice of the following topics<br>• Concentration of random vectors in high dimensions<br>• Concentration inequalities<br>• Linear and nonlinear principal component analysis (PCA)<br>• Random matrices<br>• Sparse recovery (compressed sensing) and LASSO regression<br>• Introduction to statistical learning<br>• Kernel methods and Gaussian processes<br>• Applications in signal and image processing, random networks, … |
| **Recommended Prerequisites** | Knowledge of the content of the modules<br>• 11103 : Analysis I<br>• 11104 : Analysis II<br>• 11101 : Lineare Algebra und analytische Geometrie I<br>• 11217 : Wahrscheinlichkeitstheorie<br><br>or very good knowledge of the content of the modules<br>• 11113: Mathematics IT-2 (Linear Algebra)<br>• 11213: Mathematics IT-3 (Analysis)<br>• as well as of the content one of the modules<br>- 11917 : Mathematik W-3 (Statistik) |

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| | - 11926 : Statistik für Anwender<br>- 11212 : Statistics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • C.M. Bishop. Pattern Recognition and Machine Learning. Springer, 2006.<br>• D.P. Dubhashi, A. Panconesi. Concentration of Measure for the Analysis of Randomized Algorithms, Cambridge University Press, 2009.<br>• R. van Handel. Probability in High Dimension. Lecture Notes, Princeton University, 2016.<br>• R. Vershynin. High-Dimensional Probability: An Introduction with Applications in Data Science, Cambridge University Press, 2018 |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of a semester project<br><br>**Final module examination:**<br>• Project presentation, 45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Stochastics“ or in complex „Optimization “<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Specialisation“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Specialisation“, in limited extend<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Learning and Reasoning“<br>• Study programme Informatik B.Sc.: Compulsory elective module in „Applied Mathematics“ or in field of application „Mathematics“<br>• Study programme Informatik M.Sc.: Compulsory elective module in „Mathematics“ or in field of application „Mathematics“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“ |
| **Module Components** | • Lecture: Mathematical Data Science<br>• Accompanying exercise |
| **Components to be offered in the Current Semester** | No assignment |

# Module 12979 Internet Measurements and Forensics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 12979 | Compulsory elective |

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|---|---|
| **Modul Title** | **Internet Measurements and Forensics**<br>Internet-Messungen und Forensik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Hohlfeld, Oliver |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | This course will give a detailed introduction on how to empirically measure large communication systems on the example of the Internet as the largest communication network. The focus in on the explanation of methods for conducting such large-scale assessments to i) understand complex systems and ii) assesses their security properties. The course aims at familiarizing students with key aspects of Internet traffic, Internet protocol use and security, and methods to conduct large-scale studies for security. It will also discuss how to use measurement data for network forensics. |
| **Contents** | • Analyzing Internet naming: The domain name system and its security<br>• Internet traffic characteristics and measurement approaches (e.g., sampling, aggregation)<br>• Internet control plane analysis and robustness<br>• Internet-wide probing for liveness / security<br>• Strategies for sound measurements<br>• Internet application security measurement strategies<br>• Internet security infrastructures and network forensics<br><br>How does Internet traffic look like? Are there some characteristic properties? How and where is it possible to improve the Internet, and how can those improvements be tested? How can the previous questions be addressed, and what technical challenges does one face while monitoring? How can data privacy be ensured? Is there something to bear in mind when analyzing such measurements in a statistical manner? Is it possible to generate realistic traffic based on statistical characteristics? |

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| **Recommended Prerequisites** | Knowledge about foundational aspects of computer networks (e.g., basic protocols such as IP, TCP, HTTP) as thought in introductory courses on computer networks is expected. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 1 hours per week per semester<br>Self organised studies - 135 hours |
| **Teaching Materials and Literature** | • Kurose, J. F.; Ross, K. W.: Computer Networking: A Top Down Approach<br>• Crovella, M; Krishnamurthy, B; Internet Measurement: Infrastructure, Traffic and Applications |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercise sheets<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30-45 min. (with small number of participants)<br><br>In the first lecture it will be announced, if the examination will be offered in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Informatik M.Sc.: Compulsory elective module in complex „Angewandte und technische Informatik“ (level 400)<br>• Study programme Cyber Security M.Sc.: Compulsory elective module in complex „Computer Science“ and in complex „Cyber Security Methods“<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Hardware-basierte Systeme: Elektrotechnik, Informationstechnik und Sensorik“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“ |
| **Module Components** | • Lecture: Internet Measurements and Forensics<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13017 Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13017 | Compulsory elective |

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|---|---|
| **Modul Title** | **Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations**<br>Mikrowellen- und Millimeterwellensensoren für die Biomedizin: Anwendungen und physikalische Grundlagen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wenger, Christian |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | Students are familiar with the basic concepts of microwave and millimeter wave sensors in biomedicine. They know how to apply and focus their wide-ranging knowledge from the basic studies to a current field of research and development.<br>In addition, the students have consolidated additional skills such as cooperation, accurateness, perseverance, curiosity, initiative, frustration tolerance and the like. |
| **Contents** | **Measurement and circuit fundamentals for high-frequency (HF) sensors**<br>• Scattering parameters<br>• HF wires: features and models<br>• Antennas as near-field and far-field sensors<br>• Resonators<br>• Electric interferometers<br>• Transceiver<br>• Vector network analyzers (VNA) and power detectors<br><br>**Dielectric properties of materials in biomedicine**<br>• Dielectric properties of mixtures (binary, disperse)<br>• Dielectric properties of cells<br>• EEffective permittivity of layered materials<br>• Dielectric phantoms for emulating human tissue |

**Integrated HF Sensors for Biomedicine**
- Colpitts oscillator for classifying plaque in arteries
- Open coaxial cable with VNA as dielectric sensor
- Metamaterial resonator for measuring alcohol concentration
- Interferometer as cytometer
- On-Chip Transducer with integrated Microfluidics for Lab-on-Chip
- Millimeter wave transceiver for gas spectroscopy
- Reflectometer for measuring the dehydration of the skin

**Content Laboratory**
- Getting familiar with the design and simulation software ADS (Keysight)
- Design of wire-based dielectric sensors on printed circuit boards in the millimeter wave range
- Measurement of liquid materials using self-developed sensors and evaluation based on dielectric models
- Comparison measurements with a continuous wave interferometer
- On-Wafer measurements of existing integrated sensors and evaluation

**Recommended Prerequisites**
- Knowledge of the content of the modules in experimental physics.

**Mandatory Prerequisites**
none

**Forms of Teaching and Proportion**
Lecture - 2 hours per week per semester
Exercise - 2 hours per week per semester
Self organised studies - 120 hours

**Teaching Materials and Literature**
- Pozar, D. M. (2009). Microwave engineering. John Wiley & Sons.
- Razavi, B. (2008), Fundamentals of microelectronics. Wiley.
- Razavi, B. & Behzad, R. (1998). RF microelectronics (Vol. 2). New Jersey: Prentice Hall
- Niknejad, A. M. & Hashemi, H. (Eds.). (2008). mm-Wave silicon technology: 60 GHz and beyond. Springer Science & Business Media
- Vander Vorst, A., Rosen, A., & Kotsuka, Y. (2006). RF/microwave interaction with biological tissues (Vol. 181). John Wiley & Sons.

Training materials, measuring equipment and simulation software will be provided.

**Module Examination**
Final Module Examination (MAP)

**Assessment Mode for Module Examination**
- Oral examination 30-45 minutes

**Evaluation of Module Examination**
Performance Verification – graded

**Limited Number of Participants**
none

**Remarks**
- Study programme Physics B.Sc.: Compulsory elective module in complex „Physical Specialised Module“
- Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“

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| **Module Components** | • Lecture: Microwave and Millimeter Wave Sensors for Biomedicine: Applications and Physical Foundations<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13034 Internship

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13034 | Compulsory elective |

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|---|---|
| **Modul Title** | **Internship**<br>Berufspraktikum |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 12 |
| **Learning Outcome** | After successfully completing the internship as part of the minor suject in the Master's degree programme in Physics, the students know how to apply, supplement and deepen the learned material in an environment typical for professional practice. The students have the ability to familiarise themselves with the diverse tasks of application and research-related fields of activity and to cope with the frequently changing tasks that they will encounter in their later professional life. They possess general methodological skills such as knowledge management, knowledge transfer and planning skills.<br>In addition, the students can use their social competences such as teamwork, cooperation and integration skills, as well as other individual competences such as self-efficacy, diligence, perseverance, time management and initiative in a purposefully. |
| **Contents** | The students gain knowledge about characteristic areas which are typical for the job of a physicist. The knowledge gained in the study will be implemented for example through involvement in project work. Further details are regulated by the internship regulations. |
| **Recommended Prerequisites** | • Knowledge in physics within the frame of a bachelor course in physics. |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Practical training - 360 hours |
| **Teaching Materials and Literature** | • Internspecific literature provided by the respective supervisor. |

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| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Written internship report, 3000 - 5000 words, 50%<br>• Public final presentation, 30 minutes, 50%<br><br>According to the intership regulations internship, report and presentation are assessed and graded by the respective supervisor. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M. Sc.: Compulsory elective module in complex „Minor Subject“<br><br>Further regulation can be obtained from the internship regulations. |
| **Module Components** | • Consultations on appointment |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13254 Image Based Measurement Techniques for Aerodynamics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13254 | Compulsory elective |

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|---|---|
| **Modul Title** | **Image Based Measurement Techniques for Aerodynamics**<br>Bildgebende Messverfahren in der Aerodynamik |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Schröder, Andreas |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | The students will learn the (laser-) optical and electronic basics as well as suitable digital image processing and evaluation methods for various 2D- and 3D-image based measurement- and visualization methods (e.g. PIV, LPT, LIF, PSP, TSP, BOS, DIC etc.) for aerodynamics. Through relevant applications to unsteady and rotational flows and on surfaces of bodies immersed in such flows, the students will get to know the limits (systematic and signal-to-noise ratio-related measurement uncertainties) and possibilities of different optical (non-intrusive) measurement techniques. Equipped with this knowledge, the students learn the use of (statistical) analysis tools that can be applied to the experimentally achieved instantaneous or time-resolved planar or volumetric flow field data from industrial flow facilities or wind- and water tunnels in order to achieve a deeper understanding of the investigated flow properties and related (dynamical) forces and moments. The quantitative flow measurement data and their analysis should in turn enable the students to directly relate to the underlying Navier-Stokes equations, to validation procedures for (U)RANS and other CFD methods, to different models and dynamics of vortical flow structures, to aero-elastically coupled fluid-structure interactions or to the field of aero-acoustics. |
| **Contents** | Due to enormous advances in the field of digital camera, laser and LED technologies for spatially and temporally highly-resolved image acquisition on the one hand and the increased performance of computers and GPU clusters for digital image processing on the other hand, optical measurement techniques are in a rapid upswing and are increasingly replacing classic, sensor-based measurement techniques. In the lecture the theoretical, optical and technical basics, |

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| | as well as current further developments and applications of image based measurement methods in the areas of aerodynamics, fluid mechanics, and aero-elasticity, as well as partly in aeroacoustics will be presented. In addition to methods that aim at the acquisition of aero-dynamically and -elastically relevant measurement variables such as the distribution of pressure, deformation, temperature or wall shear stress on model surfaces, optical methods for the planar and volumetric measurements of scalar quantities in flows, such as density, concentration or temperature are discussed. However, the greater part of the lecture will deal with the theory, application and evaluation of particle-based measurement methods for the planar and volumetric determination of instantaneous and time-resolved velocity, acceleration and pressure fields in unsteady flows, as well as with the possibilities of the subsequent data assimilation and analysis tools. |
| **Recommended Prerequisites** | • English language skills<br>• Basic knowledge in fluid mechanics and optics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Raffel et al. PIV a practical guide, 3rd edition (2018)<br>• Tropea C., Yarin A.L., Foss J.F. (Eds.): Handbook of Experimental Fluid Mechanics, Springer Verlag (2007)<br>• Schröder A., Willert C. (Eds.): Particle Image Velocimetry – New developments and recent applications, Springer Verlag (2007)<br>• Selected literature |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Completion of 7 practical training exercises and preparation of the respective reports of about 3 pages each (1/3 of the module grade).<br>• Oral examination of approx. 30 min. duration (2/3 of the module grade) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | • Lecture Image based measurement techniques for aerodynamics<br>• Exercise Image based measurement techniques for aerodynamics<br>• Exam Image based measurement techniques for aerodynamics |
| **Components to be offered in the Current Semester** | **352102** Lecture<br>Image based measurement techniques for aerodynamics - 2 Hours per Term<br>**352103** Exercise/Practical training<br>Image based measurement techniques for aerodynamics - 2 Hours per Term |

# Module 13299 Dimensional Analysis and Experimentation

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13299 | Compulsory elective |

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|---|---|
| **Modul Title** | **Dimensional Analysis and Experimentation**<br>Dimensionsanalyse und Experiment |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Harlander, Uwe |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Goal is to use dimensional analysis to bring together the results of experiments and theory/computations in a concise but exact form. Moreover we will show that many phenomena in nature, engineering or society exhibit the remarkable property of self-similarity. In the lecture we highlight the tight connection between dimensional analysis and scaling laws. The latter is a powerful concept of understanding experimental data of fluid mechanics. |
| **Contents** | • Numbers and units<br>• Dimensions and variables<br>• Dimensional analysis<br>• Similarity and intelligent experimentation<br>• Nondimensionalisation of equations<br>• Self-similarity and power laws<br>• Models of fluid mechanics |
| **Recommended Prerequisites** | Basics of analysis and fluid dynamics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Book "Dimension analysis and intelligent experimentation" von A.C. Palmer<br>• Book "Scaling" von G.I. Barenblatt |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |

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| **Assessment Mode for Module Examination** | Prerequisite:<br>• two tests for exercise (ungraded) until 10th lecture week<br><br>Final Module Examination:<br>• Written exam, 90 minutes |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | No offer in winter semester 2026/27! |
| **Module Components** | VL Dimensional Analysis and Experimentation<br>SEM Dimensional Analysis and Experimentation<br>PRÜ Dimensional Analysis and Experimentation |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13517 CFD Seminar

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13517 | Compulsory elective |

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| **Modul Title** | **CFD Seminar**<br>CFD-Seminar |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Schmidt, Heiko |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful participation the students are able to evaluate distinguished fluid mechanical problems from a numerical point of view. |
| **Contents** | The numerically evaluated topics are:<br>• Laminar, turbulent, compressible and incompressible flows in technical flows, geophysics, meteorology and reactive flows. |
| **Recommended Prerequisites** | • Basics of numeric and fluid mechanics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Seminar - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • Stephen B. Pope, Turbulent Flows, 2000<br>• Joel H. Ferziger, Numerische Strömungsmechanik, 2007 |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Presentation; 20 min (1/3 of grade for the quality of the preparation and 1/3 oral presentation) and<br>• written report; 10 pages (1/3 of grade). |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |

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| **Module Components** | • SEM CFD Seminar |
| **Components to be offered in the Current Semester** | **350411** Seminar<br>CFD Seminar - 2 Hours per Term |

# Module 13518 Image Based Measurement Techniques for Fluid Mechanics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13518 | Compulsory elective |

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|---|---|
| **Modul Title** | **Image Based Measurement Techniques for Fluid Mechanics**<br>Bildgebende Messverfahren in der Strömungsmechanik |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Schröder, Andreas |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | The students will learn the (laser-) optical and electronic basics as well as suitable digital image processing and evaluation methods for various 2D- and 3D image based measurement- and visualization methods (e.g. PIV, LPT, LIF, PSP, TSP, BOS, DIC etc.) for fluid mechanics. Through relevant applications to unsteady and rotational flows and on surfaces of bodies immersed in such flows, the students will get to know the limits (systematic and signal-to-noise ratio-related measurement uncertainties) and possibilities of different optical (non-intrusive) measurement techniques. Equipped with this knowledge, the students learn the use of (statistical) analysis tools that can be applied to the experimentally achieved instantaneous or time-resolved planar or volumetric flow field data from industrial flow facilities or wind- and water tunnels in order to achieve a deeper understanding of the investigated flow properties and related (dynamical) forces and moments. The quantitative flow measurement data and their analysis should in turn enable the students to directly relate to the underlying Navier-Stokes equations, to validation procedures for (U)RANS and other CFD methods, to different models and dynamics of vortical flow structures, to aero-elastically coupled fluid-structure interactions or to the field of aero-acoustics. |
| **Contents** | Due to enormous advances in the field of digital camera, laser and LED technologies for spatially and temporally highly-resolved image acquisition on the one hand and the increased performance of computers and GPU clusters for digital image processing on the other hand, optical measurement techniques are in a rapid upswing and are increasingly replacing classic, sensor-based measurement techniques. In the lecture the theoretical, optical and technical basics, |

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| | as well as current further developments and applications of image-based measurement methods in the areas of aerodynamics, fluid mechanics, and aero-elasticity, as well as partly in aeroacoustics will be presented. In addition to methods that aim at the acquisition of aero-dynamically and -elastically relevant measurement variables such as the distribution of pressure, deformation, temperature or wall shear stress on model surfaces, optical methods for the planar and volumetric measurements of scalar quantities in flows, such as density, concentration or temperature are discussed. However, the greater part of the lecture will deal with the theory, application and evaluation of particle-based measurement methods for the planar and volumetric quantification of instantaneous and time-resolved velocity-, acceleration- and pressure fields in unsteady flows, as well as with the possibilities of the subsequent data assimilation and analysis tools. |
| **Recommended Prerequisites** | • English language skills<br>• Basic knowledge in fluid mechanics and optics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Practical training - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Raffel et al. PIV a practical guide, 3rd edition (2018)<br>• Tropea C., Yarin A.L., Foss J.F. (Eds.): Handbook of Experimental Fluid Mechanics, Springer Verlag (2007)<br>• Schröder A., Willert C. (Eds.): Particle Image Velocimetry – New developments and recent applications, Springer Verlag (2007)<br>• Selected literature |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Completion of 7 practical training exercises and preparation of the respective reports of about 3 pages each (1/3 of the module grade).<br>• Oral examination of approx. 30 min. duration (2/3 of the module grade) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | • VL Image based measurement techniques for fluid mechanics<br>• ÜB Image based measurement techniques for fluid mechanics<br>• P Image based measurement techniques for fluid mechanics |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13843 Scientific Computing

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13843 | Compulsory elective |

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|---|---|
| **Modul Title** | **Scientific Computing**<br>Methoden des Scientific Computing |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Breuß, Michael<br>Prof. Dr.-Ing. Oevermann, Michael |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 8 |
| **Learning Outcome** | <p lang="en-US" style="line-height: 100%; margin-bottom: 0in;">Upon successful completion of the module, students will have acquired advanced knowledge for understanding modern numerical methods across a wide range of fields in science and engineering. |
| **Contents** | <p lang="en-US" style="line-height: 100%; margin-bottom: 0in;">This module aims to teach advanced methods of scientific computing. The methodological focus lies on advanced computational techniques in numerical linear algebra and related fields. <p lang="en-US" style="line-height: 100%; margin-bottom: 0in;">Topics include: a selection of advanced methods for computing eigenvalues and eigenvectors, singular value decomposition, numerical aspects of least-squares approximation, and a selection of matrix factorization methods. |
| **Recommended Prerequisites** | Knowledge of the content of the modules:<br>• 11925 *Grundlagen der Numerischen Mathematik*<br>• 11943 *Grundlagen des Wissenschaftlichen Rechnens*<br>• 11414 *Funktionentheorie und Partielle Differentialgleichungen*<br><br>as well as programming skills, typically Matlab and C / Fortran |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 3 hours per week per semester<br>Exercise - 1 hours per week per semester<br>Practical training - 2 hours per week per semester |

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| | Self organised studies - 150 hours |
| **Teaching Materials and Literature** | The literature in use may change over time and will be announced at the first class meeting. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Three written tests, 30 minutes each (each 30%)<br>• Presentation of the practical training, 15 minutes (10%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Numerics“<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Specialisation“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Specialisation“, in limited extend<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Advanded Methods“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Numerics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Advanced Mathematical Methods in Data Science“ |
| **Module Components** | • Lecture: „Scientific Computing“<br>• Accompanying exercise<br>• Accompanying laboratory<br>• Related examination |
| **Components to be offered in the Current Semester** | **130320** Lecture/Exercise<br>Scientific Computing - 4 Hours per Term |

# Module 13844 Functional Analysis

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13844 | Compulsory elective |

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|---|---|
| **Modul Title** | **Functional Analysis**<br>Funktionalanalysis |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wachsmuth, Gerd |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 8 |
| **Learning Outcome** | The students have<br>• expanded and intensified their knowledge from previous modules of Analysis and Algebra<br>• competently mastered definitions and interrelations within abstract spaces<br>• become acquainted with applications in Numerics, Optimization, and Physics<br>• acquired basic knowledge for advanced modules<br>• became familiar with fundamental techniques of proof<br>• improved their logical way of thinking by solving problems in abstract spaces<br>• further developed their abilities for independent scientific work by treating themes from Functional Analysis |
| **Contents** | • **Normed spaces**<br>completion, separable spaces, Lebesgue spaces, spaces of continuous and differentiable functions, Sobolev spaces<br>• **Linear and continuous operators**<br>Projection and adjoint operators, topological dual spaces, completely continuous operators, weak convergence and reflexivity<br>• **Main theorems**<br>Weierstrass, Hahn-Banach, Schauder, the openmapping, the closed graph<br>• **Hilbert spaces**<br>Spectral theorem for selfadjoint, completely continuous operators |
| **Recommended Prerequisites** | Knowledge of the content of the modules |

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| | • 11103 *Analysis I*<br>• 11104 *Analysis II*<br>• 11201 *Analysis III* |
| **Mandatory Prerequisites** | No successful participation in module *11303 - Funktionalanalysis*. |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • Aubin, J.-P.: Applied Functional Analysis, Wiley, 2000, https://doi.org/10.1002/9781118032725<br>• Brezis, H.: Functional Analysis, Sobolev Spaces and Partial Differential Equations, Springer, 2011, https://doi.org/10.1007/978-0-387-70914-7<br>• Rudin, W.: Functional Analysis, McGraw Hill, 1991 |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of homework<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30 min. (with small number of participants)<br><br>In the first lecture it will introduced, if the examination will organized in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Kombinatorik“<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Advanded Methods“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Combinatorics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Fundamentals of Data Science“<br><br>If there is no need that the module is taught in English, alternatively the german version 11303 „Funktionalanalysis“ may beread instead. |
| **Module Components** | • Lecture: Functional Analysis<br>• Accompanying exercises<br>• Related examination |

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| **Components to be offered in the Current Semester** | **130912** Examination<br>Functional Analysis / Funktionalanalysis -- Reexamination |

# Module 13863 Mathematical Statistics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13863 | Compulsory elective |

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|---|---|
| **Modul Title** | **Mathematical Statistics**<br>Mathematische Statistik |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wunderlich, Ralf<br>Prof. Dr. rer. nat. Hartmann, Carsten |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 8 |
| **Learning Outcome** | The students<br>• are skilled in probability theory,<br>• know the basic statistical models and learn how to correctly use statistical methods<br>• can study advanced topics in stochastics<br>• understand statistical methods thoroughly to avoid biased and false conclusions<br>• are experienced in autonomously doing research based on specific applications. |
| **Contents** | • Descriptive statistics (central tendency and variation, quantiles, linear regression)<br>• Parameter estimation (point estimates, confidence intervals, Bayesian estimastion, sufficient statistic)<br>• Hypothesis testing (statistical tests, Neyman-Pearsonlemma, one- and two-sided tests)<br>• Linear models (regression and variance analysis, linear classification, Gauss-Markov theorem)<br>• Applications and use of statistical software |
| **Recommended Prerequisites** | Knowledge of the content of module<br>• 11217: Probability Theory |
| **Mandatory Prerequisites** | No successful participation in module *11331 - Mathematische Statistik*. |
| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester |

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| | Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • G. Casella, R.L. Berger. Statistical Inference. Duxbury, 2002<br>• W.R. Pestman. Mathematical Statistics. De Gruyter 1998<br>• Jun Shao, Mathematical Statistics, Springer, 2003, DOI: 10.1007/b97553<br>• H.-O. Georgii, Stochastics: Introduction to Probability and Statistics, De Gruyter, 2008 (DOI: 10.1515/9783110206760) |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of homework<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30 min.<br><br>In the first lecture it will introduced, if the examination will organized in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Mathematik B.Sc.: Compulsory elective module in complex „Specialisation“<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Specialisation“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Informatik B.Sc.: Compulsory elective module in „Applied Mathematics“ or in field of application „Mathematics“<br>• Study programme Informatik M.Sc.: Compulsory elective module in „Mathematics“ or in field of application „Mathematics“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Stochastics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Advanced Mathematical Methods in Data Science“ |
| **Module Components** | • Lecture: Mathematical Statistics<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | **130552** Examination<br>Mathematical Statistics/Mathematische Statistik -- Reexamination |

# Module 13874 Introduction to Numerical Linear Algebra

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13874 | Compulsory elective |

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|---|---|
| **Modul Title** | **Introduction to Numerical Linear Algebra**<br>Einführung in die Numerische Lineare Algebra |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Oevermann, Michael |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the course the students know and understand classic and state of the art numerical methods and algorithms for solving linear systems of equations and to compute eigenvalues and eigenvectors. Through programming exercises they have acquired the practical skills to implement and validate numerical methods for scientific computing applications. The students have learned to use the programming language Python and common Python libraries/toolboxes (Numpy, Scipy) for an efficient and performant implementation methods used in scientific computing. |
| **Contents** | The module focuses on methods and algorithms suitable for solving linear sets of equations as they typically arise in many applications such as solving/discretzising partial differential equations in engineering sciences or machine learning algorithms. In particular we will cover:<br>• Classic iterative methods for solving linear systems of equations (Jacobi, Gauß-Seidel, SOR)<br>• Projection type methods for solving linear systems of equations (CG, GMRES)<br>• Direct methods for sparse linear systems of equations<br>• Jacobi eigenvalue algorithm, power iteration, QR iteration<br><br>Additionally, we will address practical issues of solving large sparse systems of linear equations such as storage schemes and parallelisation strategies. |

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| **Recommended Prerequisites** | Basic knowledge of mathematics as conveyed by mathematical courses in computer science or engineering from the first three to four semesters, e.g.:<br>• Module 11101 *Lineare Algebra und analytische Geometrie I*, and<br>• Module 11103 *Analysis I*<br><br>or<br>• Module 11112 *Mathematik IT-1 (Diskrete Mathematik)*<br>• Module 11113 *Mathematik IT-2 (Lineare Algebra)*<br>• Module 11213 *Mathematik IT-3 (Analysis)*<br><br>or<br>• Module *Höhere Mathematik - T1*<br>• Module 11108 *Höhere Mathematik - T2*<br>• Module 11206 *Höhere Mathematik - T3* |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • G. H. Golub, C. F. van Loan: Matrix Computations<br>• L. N. Trefethen, D. Bau: Numerical Linear Algebra, SIAM<br>• Y. Saad: Iterative Methods for Sparse Linear Systems<br>• T. A. Davis: Direct Methods for Sparse Linear Systems |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • three written examinations during the lecture or exercise period, 30 minutes each (1/3 each; 70% in total)<br>• three programming tasks (1/3 each; 30% in total) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Numerics“<br>• Study programme Informatik B.Sc.: Compulsory elective module in complex „Mathematik“ or in field of application „Mathematik“<br>• Study programme Informatik M.Sc.: Compulsory elective module in complex „Mathematik“ or in field of application „Mathematik“<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Advanded Methods“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Numerics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Fundamentals of Data Science“ |

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| | Change from MAP to MCA. Registration for repitition of the MAP module only possible via Student Services. |
| **Module Components** | • Lecture: Introduction to Numerical Linear Algebra<br>• Accompanying exercise |
| **Components to be offered in the Current Semester** | **131130** Examination<br>Introduction to Numerical Linear Algebra (Wiederholung) |

# Module 13906 Data Exploration and System Management Using Artificial Intelligence / Machine Learning

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13906 | Compulsory elective |

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|---|---|
| **Modul Title** | **Data Exploration and System Management Using Artificial Intelligence / Machine Learning**<br>Datenexploration und Systemmanagement mit Künstlicher Intelligenz / Maschinellem Lernen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. hab. Jablonski, Ireneusz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After completion of the module, students will have an overview of the basic operations available for processing datasets measured in systems of any nature (e.g., physical, technical, biological, financial, etc.) and will be able to relate these operations to AI/ML-based methods and tools dedicated to a specific task. The students understand real world problems and can explain them using computer simulations. They know how to apply the acquired knowledge to an individual project, including increased skills in preparing project documentation and public presentation. |
| **Contents** | The subject of the module are the classes of real-world problems that can be solved by data exploration using AI/ML methods. This includes, for example, anomaly/outlier detection, data decomposition and feature selection, data fusion, prediction, decision support. A mapping between problems and available AI/ML methods will be presented.<br>The project consists in solving a self-defined problem using a selected AI/ML technique and computer simulations. The software procedure together with a project report will be created by student. |
| **Recommended Prerequisites** | • Knowledge of mathematics, especially statistics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester |

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| | Study project - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Hastie T., Tibshirani R., Friedman J.: The elements of statistical learning. Data mining, inference, and prediction. Springer, 2nd edition, New York 2009.<br>• Kulkarni S., Harman G.: Elementary introduction to statistical learning theory. Wiley & Sons Inc., New Jersey 2011. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of the project task, 30 h<br><br>**Final module examination:**<br>• Written examination, 90 min. OR<br>• Oral examination, 30-45 min. (with small number of participants)<br><br>In the first lecture it will be announced, wheter the examination will be organised in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 20 |
| **Remarks** | • Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Learning and Reasoning“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“ |
| **Module Components** | • Lecture: Data exploration and system management using AI/ML<br>• Accompanying project<br>• Related examination |
| **Components to be offered in the Current Semester** | **152250** Lecture<br>Data exploration and system management using artificial intelligence/ machine learning - 2 Hours per Term<br>**152251** Practical training<br>Data exploration and system management using artificial intelligence/ machine learning - 2 Hours per Term<br>**152252** Examination<br>Data exploration and system management using artificial intelligence/ machine learning |

# Module 13908 Experimental Techniques in Physics Supported with Artificial Intelligence / Machine Learning

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13908 | Compulsory elective |

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| **Modul Title** | **Experimental Techniques in Physics Supported with Artificial Intelligence / Machine Learning**<br>Experimentelle Techniken in der Physik gestützt durch Künstliche Intelligenz / Maschinelles Lernen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. hab. Jablonski, Ireneusz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After completion of the module, students will have an overview on methods and tools used for experimentation with physical systems. They know the role of artificial intelligence/machine learning (AI/ML) in inference with experimental data processing. They are able to apply the acquired knowledge in computer experiments realized during laboratories. |
| **Contents** | The subject of the module is the fundamentals of experiment design, including the theoretical and practical aspects of experiment planning and execution. This includes, for example, the role of observation and measurement in cognition process, data collection and processing with the use of statistical and AI/ML methods, data and system modeling, computer simulation, and planning of experiment.<br>The laboratory will use computer simulation to solve selected problems of experimentation, e.g. forward and inverse modeling, signal reconstruction, model identification, experiment planning. Statistical and AI/ML techniques will be used in exemplary tasks. The form of the class includes the realization of tasks under supervision and solving self-defined problems. |
| **Recommended Prerequisites** | • Knowledge of mathematics, especially statistics |
| **Mandatory Prerequisites** | none |

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| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Practical training - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Brandt S.: Data analysis. Statistical and computational methods for scientists and engineers. 4th Ed., Springer, Heidelberg 2014<br>• Söderstöm T., Stoica P.: System identification. Prentice Hall, Michigan, USA, 1989<br>• Lakshmanan V., Robinson S., Munn M.: Machine learning design patterns. Solutions to common challenges in data preparation, model building, and MLOps. O'Reilly, USA 2020 |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of the project task,  30 h<br><br>**Final module examination:**<br>• Written examination, 90 min. OR<br>• Oral examination, 30-45 min. (with small number of participants)<br><br>In the first lecture it will be announced, wheter the examination will organized in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 20 |
| **Remarks** | • Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Knowledge Acquisition, Representation, and Processing“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“ |
| **Module Components** | • Lecture: Data exploration and system management using AI/ML<br>• Accompanying laboratoy<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13949 Differential Geometry

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13949 | Compulsory elective |

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|---|---|
| **Modul Title** | **Differential Geometry**<br>Differentialgeometrie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Breuß, Michael |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students are familiar with the basic concepts and techniques of differential geometry and able to apply the appropriate techniques. |
| **Contents** | • Euclidean geometry<br>• Curve geometry<br>• Classic planar theory<br>• Inner planar geometry<br>• Connection of geometry with calculus and topology |
| **Recommended Prerequisites** | Knowledge of the content of the modules<br>• 11103: *Analysis I*<br>• 11104: *Analysis II*<br>• 11101: *Lineare Algebra und analytische Geometrie I* |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 3 hours per week per semester<br>Exercise - 1 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Martin Lipschutz, Schaum's Outline of Differential Geometry, Schaum Outline Series |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of homework (50% of points must be reached) |

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| | **Final module examination:**<br>• Written examination, 90 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Kombinatorik“<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Vertiefung“, in limited extend<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Knowledge Acquisition, Representation, and Processing“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Combinatorics“<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Fundamentals of Data Science“ |
| **Module Components** | • Lecture: Differential Geometry<br>• Accompanying exercise<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 13987 Electrical Power Generation and Integration of Wind Energy

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13987 | Compulsory elective |

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|---|---|
| **Modul Title** | **Electrical Power Generation and Integration of Wind Energy**<br>Elektrische Energieerzeugung und Integration von Windenergie |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Malekian Boroujeni, Kaveh |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Students will get a deep understand of wind energy technologies, including the basics of fundamental principles of wind turbines and their components. Principles of operation of wind turbines regarding important parameters will be introduced. Students will get a basic overview in grid integration and economics of wind turbines and will faced with advantages and disadvantages of fluctuating power infeed. A general overview about planning, operation and maintenance of wind turbines will be shown. |
| **Contents** | 1. General overview about wind energy<br>2. Physics of wind energy, drag and lift etc.<br>3. Construction of wind turbines, components<br>4. Operation of wind turbines: wind speed, roughness, profiles<br>5. Power generation concepts of wind turbines<br>6. Grid integration<br>7. Planning, operation, maintenance, economics |
| **Recommended Prerequisites** | Fundamental knowledge in engineering and mathematics is beneficial. |
| **Mandatory Prerequisites** | No successful participation in **11689 Power Generation from Wind Energy** |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | Students will be provided with slides and materials presented in the lessons. Further recommendations for literature will be announced in the first lectures. |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 90 minutes OR<br>• Online examination, 90 minutes OR<br>• Oral examination, 30 minutes<br><br>(The corresponding regulation for each semester will be announced in the first lecture.) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | VL + Prü Electrical Power Generation and Integration of Wind Energy |
| **Components to be offered in the Current Semester** | **320103** Lecture/Seminar<br>Electrical Power Generation and Integration of Wind Energy - 4 Hours per Term<br>**320170** Examination<br>Electrical Power Generation and Integration of Wind Energy |

# Module 13988 Electrical Power Generation and Integration of Solar Energy

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13988 | Compulsory elective |

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|---|---|
| **Modul Title** | **Electrical Power Generation and Integration of Solar Energy**<br>Elektrische Energieerzeugung und Integration von Solarenergie |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Malekian Boroujeni, Kaveh |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Students will get an introduction into photovoltaics, including the basics of fundamental principles of fabrication and operation of solar cells. Furthermore current PV technology trends and material research towards new concepts will be discussed. Presentation of basic principles of power generation and operation of solar energy. Students will get a basic understanding in grid integration of solar energy and economics of solar energy concepts. |
| **Contents** | 1. Solar insolation: Energy sources of photovoltaics<br>2. Photovoltaic technologies (Si-wafer based vs. thin-film PV) and solar cell materials<br>3. New technology trends and future concepts (e.g. floating PV)<br>4. Solar power generation and grid integration<br>5. Basic economics, installation and operation |
| **Recommended Prerequisites** | Fundamental knowledge in engineering and mathematics is beneficial. |
| **Mandatory Prerequisites** | No successful participation in **11690 Power Generation from Solar Energy.** |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | Students will be provided with slides and materials presented in the lessons. Further recommendations for literature will be announced in the first lecture. |

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| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Written examination, 90 minutes OR<br>• Online examination, 90 minutes OR<br>• Oral examination, 30 minutes<br><br>(The corresponding regulation for each semester will be announced in the first lectures.) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | VL + SEM + Prü Electrical Power Generation and Integration of Solar Energy |
| **Components to be offered in the Current Semester** | **320104** Lecture/Seminar<br>Electrical Power Generation and Integration of Solar Energy - 4 Hours per Term<br>**320174** Examination<br>Electrical Power Generation and Integration of Solar Energy |

# Module 13990 Energy Storage Technologies and Grid Integration

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13990 | Compulsory elective |

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|---|---|
| **Modul Title** | **Energy Storage Technologies and Grid Integration**<br>Energiespeichertechnologien und Netzintegration |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Malekian Boroujeni, Kaveh |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | Students will get an understanding how energy systems work and why energy storages are needed. They get an overview which “use-cases” are capable for storages. Students are able to compare the different types of storage technologies and know their advantages and disadvantages. They will have a basic overview about grid integration of storages and which problems occur with storage using in energy supply. Students will also faced with basic knowledge for economic aspects of storage production and operation costs. |
| **Contents** | 1. Introduction into energy supply and transport system<br>2. Storages for compensation of fluctuating energy infeed<br>3. Mechanical storages (e.g. flywheels, pumped hydro storage)<br>4. Electrical storages (e.g. batteries)<br>5. Gas storages, hydrogen and chemical storages<br>6. Heat storages<br>7. Grid integration of storages, using in energy supply |
| **Recommended Prerequisites** | Fundamental knowledge in engineering and mathematics ist benefical. |
| **Mandatory Prerequisites** | No successful participation in **11691 Energy Storage Technology** |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Seminar - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | Lecture scripts |
| **Module Examination** | Final Module Examination (MAP) |

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| **Assessment Mode for Module Examination** | • Written examination, 90 minutes OR<br>• Online examination, 90 minutes OR<br>• Oral examination, 30 minutes<br><br>(The corresponding regulation for each semester will be announced in the first lecture.) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | VL + SEM + Prü Energy Storage Technologies and Grid Integration |
| **Components to be offered in the Current Semester** | **320179** Examination<br>Energy Storage Technologies and Grid Integration |

# Module 14040 Computational Fluid Dynamics for Engineers

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14040 | Compulsory elective |

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|---|---|
| **Modul Title** | **Computational Fluid Dynamics for Engineers**<br>Computational Fluid Dynamics für Ingenieure |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Egbers, Christoph |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | The participation in the module enables students to understand the topic of industry-related CFD from an analytical and practical point of view. The work with industry-relevant software is brought into focus and enables the students to deal extensively with the content. This is primarily conveyed using practical examples with selected software packages. At the end of the module, the students are able to independently create and evaluate CFD simulations and draw conclusions about their applicability for industry. |
| **Contents** | CFD methods in industry<br>• Linux and network architectures<br>• Grid generators and construction of fluid mechanical solvers.<br>• Matlab, toolboxes<br>• Openfoam<br>• Ansys / CFX / Fluent Star CCM+<br>• Post processing with Paraview |
| **Recommended Prerequisites** | This course is an advanced course with respect to numerical fluid mechanics and requires a fundamental knowledge of numerical analysis and fluid mechanics. Therefore, it is suggested to have a prior knowledge in the following taught courses:<br>• Modul 31205 Strömungslehre<br>• Modul 31303 Höhere Strömungsmechanik<br>• Module 13970 Numerical Fluid Mechanics<br>• or comparable knowledge of flow and gas dynamics or numerics. |
| **Mandatory Prerequisites** | • no successful participation in 11726 CFD für Ingenieure |

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| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Lecture note |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Course Work, 5,000 words. References, table of content, tables and figures are excluded. (70%)<br>• Presentation of results, 12 min excluding examiners questions (30%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | • VL, Ü Computational Fluid Dynamics for Engineers |
| **Components to be offered in the Current Semester** | **350114** Lecture<br>Computational Fluid Dynamics for Engineers - 2 Hours per Term<br>**350117** Exercise<br>Computational Fluid Dynamics for Engineers - 2 Hours per Term |

# Module 14041 Processes in Porous Materials

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14041 | Compulsory elective |

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|---|---|
| **Modul Title** | **Processes in Porous Materials**<br>Prozesse in porösen Materialien |
| **Department** | Faculty 2 - Environment and Natural Sciences |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Klepel, Olaf |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 6 |
| **Learning Outcome** | The students acquire basic knowledge on the nature of highly porous materials (pore widths between 0.5 and 50 nm) and their characterization. They acquire knowledge of important processes which take place in highly porous materials such as adsorption and mass transport processes. By studying original scientific literature on their own, students are able to analyse scientific texts and reflect on their content in the context of the lecture material. In addition, students have acquired further personal skills related to the degree programme through communicative discussion in seminars. |
| **Contents** | • nature of porosity<br>• equilibrium adsorption and adsorption kinetics in porous materials<br>• transport processes in porous materials<br>• interplay of chemical reaction and transport processes in heterogeneous catalysis (macro kinetics)<br>• the interplay of mass transport and adsorption of molecules in porous materials investigated by temperature-programmed desorption |
| **Recommended Prerequisites** | basic knowledge of porous materials and knowledge of physical chemistry |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Seminar - 1 hours per week per semester<br>Self organised studies - 165 hours |
| **Teaching Materials and Literature** | - Video-based teaching material (asynchronous)<br>- Original scientific literature provided by the lecturer |

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| | Text books:<br>M. Baerns, A. Behr, A. Brehm, J. Gmehling, H. Hofmann, U. Onken, A. Renken, K.-O. Hinrichsen, R. Palkovits, Technische Chemie, Wiley-VCH, various editions<br>H. Scott Fogler, Elements of Chemical Reaction Engineering: Pearson New International Edition, Pearson Education Limited, Harlow, 2013 |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | 2 written exams, each 45 minutes, weighted 50% |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | Seminar |
| **Components to be offered in the Current Semester** | **220522** Seminar<br>Processes in Porous Materials - 1 Hours per Term |

# Module 14085 Graph Theory

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14085 | Compulsory elective |

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|---|---|
| **Modul Title** | **Graph Theory**<br>Graphentheorie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Köhler, Ekkehard |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Each winter semester odd year |
| **Credits** | 8 |
| **Learning Outcome** | The students<br>• Know the most important terms and connections of graph theory<br>• Are able to apply graph theoretical concepts to solve practical problems<br>• Used the example of graph theroretic topics to attain experience in self-contained scientific working |
| **Contents** | • Basic concepts, graphs, connectivity, trees<br>• Matchings, colorings, flows<br>• Hall's theorem, König's theorem, chromatic number, Menger's theorem<br>• Planar graphs, Euler characteristic, Kuratowski's theorem, duality, cycle bases<br>• Ethical responsibility in the application of models, algorithms and results |
| **Recommended Prerequisites** | Knowledge of the content of the modules<br>• 11101: Lineare Algebra und analytische Geometrie I<br>• 12868: Algorithmische Diskrete Mathematik<br>or<br>• 11112: Mathematik IT-1 (Diskrete Mathematik)<br>• 11113: Mathematik IT-2 (Lineare Algebra) |
| **Mandatory Prerequisites** | • No successful participation in module 11415 Graphtheorie |

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| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | • D.B. West: Introduction to Graph Theory. (Prentice Hall, 1996)<br>• R. Diestel: Graphentheorie. (Springer,1996) |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite for final module examination:**<br>• Successful completion of homework (fortnightly) and successful completion of tests (approx. 4 tests of 15-30 minutes each, written during the lecture period)<br><br>**Final module examination:**<br>• Written examination, 90 min. **OR**<br>• Oral examination, 30 min.<br><br>During the first class meeting, notice will be given on how the prerequisite will be structured and whether the examination will be in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Analysis / Algebra / Kombinatorik”<br>• Study programme Mathematics M.Sc.:Compulsory elective module in complex „Analysis / Algebra / Combinatorics”<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Advanced Mathematical Methods in Data Science”<br>• Study programme Mathematik B.Sc.: Compulsory elective module in complex „Vertiefung”, in limited extend<br>• Study programme Wirtschaftsmathematik B.Sc.: Compulsory elective module in complex „Vertiefung”, in limited extend<br>• Study programme Informatik B.Sc.: Compulsory elective module in „Praktische Mathematik” or in field of application „Mathematik”<br>• Study programme Informatik M.Sc.: Compulsory elective module in „Mathematik” or in field of application „Mathematik”<br>• Study programme Künstliche Intelligenz B.Sc.: Compulsory elective module in complex „Wissensakquise, -repräsentation und -verarbeitung”<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Software-basierte Systeme”<br>• Study programme Artificial Intelligence M.Sc.: Compulsory elective module in complex „Knowledge Acquisition, Representation, and Processing” |

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|---|---|
| | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject” |
| **Module Components** | • Lecture: Graph Theory<br>• Accompanying exercises<br>• Related examination |
| **Components to be offered in the Current Semester** | **130413** Examination<br>Graph Theory - Reexamination - 2 Hours per Term |

# Module 14293 Porous Materials

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14293 | Compulsory elective |

| | |
|---|---|
| **Modul Title** | **Porous Materials**<br>Poröse Materialien |
| **Department** | Faculty 2 - Environment and Natural Sciences |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Klepel, Olaf |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 6 |
| **Learning Outcome** | The students acquire comprehensive knowledge on important classes of porous materials, their preparation and characterization. By studying original scientific literature on their own, students are able to analyse scientific texts and reflect on their content in the context of the lecture material. In addition, students have acquired further personal skills related to the degree programme through communicative discussion in seminars. |
| **Contents** | • nature of porosity<br>• textural characterization of porous materials by adsorption methods<br>• material classes: zeolites, activated carbons, silica gel, porous glass, metal organic frameworks, porous polymers, ordered mesoporous material, membranes |
| **Recommended Prerequisites** | Knowledge of inorganic, organic and physical chemistry |
| **Mandatory Prerequisites** | Module 12276 Porous Materials was not successfully completed. |
| **Forms of Teaching and Proportion** | Seminar - 1 hours per week per semester<br>Self organised studies - 165 hours |
| **Teaching Materials and Literature** | • Video-based teaching material (asynchronous)<br>• Original scientific literature |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | 2 written exams, each 45 minutes, weighted 50% |

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| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | Cannot be taken if Module 12276 Porous Materials has already been taken or is being taken at the same time. |
| **Module Components** | Seminar Porous Materials |
| **Components to be offered in the Current Semester** | **220526** Seminar<br>Porous Materials - 1 Hours per Term |

# Module 14316 Antennas I

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14316 | Compulsory elective |

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|---|---|
| **Modul Title** | **Antennas I**<br>Antennen I |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr.-Ing. habil. Ndip, Ivan |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be acquainted with the fundamental theory of antenna radiation, the main differences between hertzian and magnetic dipole radiators as well as with the radiation characteristics of different configurations of dipole, monopole and loop antennas. The students will also be familiar with the theory of linear and planar antenna arrays as well as with methods for antenna synthesis. Furthermore, they will know techniques for measuring the S-parameters of antennas. |
| **Contents** | • Introduction<br>• Fundamental theory of antenna radiation<br>• Antenna parameters from circuit and field points of views<br>• Hertzian and magnetic dipole radiators<br>• Linear wire antennas: Dipole and monopole antennas<br>• Loop antennas<br>• Antenna arrays<br>• Antenna synthesis<br>• Antenna measurements: S-parameter |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |

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|---|---|
| **Teaching Materials and Literature** | • Lecture notes<br>• Constantine A. Balanis: Antenna Theory, Analysis and Design, Wiley; 4th Edition, 2016<br>• John D. Kraus: Antennas For All Applications, McGraw-Hill , 3rd Edition, 2003<br>• Klaus W. Kark: Antennen und Strahlungsfelder, Springer Vieweg; 9th Edition, 2022<br>• Warren L. Stutzman, Gary A. Thiele: Antenna Theory and Design, Wiley; 3rd Edition, 2012 |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral exam, 30-45 min. OR<br>• Written exam, 90 min.<br><br>In the first lectures it will be announced whether the examination will be conducted in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Circuit Design”<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Hardware-basierte Systeme"<br><br>In order to acquire practical knowledge, students are recommended to also take the course "Antenna Design Laboratory I (14318)". |
| **Module Components** | • Lecture: Antennas I<br>• Exercise to the lecture<br>• Related examination |
| **Components to be offered in the Current Semester** | **112320** Lecture<br>Antennas I - 2 Hours per Term<br>**112321** Exercise<br>Antennas I - 2 Hours per Term<br>**112322** Examination<br>Antennas I |

# Module 14317 Antennas II

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14317 | Compulsory elective |

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|---|---|
| **Modul Title** | **Antennas II**<br>Antennen II |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr.-Ing. habil. Ndip, Ivan |
| **Language of Teaching / Examination** | English |
| **Duration** | 6 semesters |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be acquainted with the theory and characteristics of a variety of antenna configurations used in the development of modern wireless systems. Furthermore, the students know methods for measuring the radiation pattern and gain of antennas. |
| **Contents** | • Introduction<br>• Aperture antennas<br>• Horn antennas<br>• Microstrip patch antennas<br>• Reflector antennas<br>• Travelling wave antennas and broadband antennas<br>• Measurements of antennas: Radiation pattern and gain<br>• Application of antennas in wireless systems |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Lecture notes<br>• Constantine A. Balanis: Antenna Theory, Analysis and Design, Wiley; 4th Edition, 2016 |

| | |
|---|---|
| | • John D. Kraus: Antennas For All Applications, McGraw-Hill , 3rd Edition, 2003<br>• Klaus W. Kark: Antennen und Strahlungsfelder, Springer Vieweg; 9th Edition, 2022<br>• Warren L. Stutzman, Gary A. Thiele: Antenna Theory and Design, Wiley; 3rd Edition, 2012 |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral exam, 30-45 min. OR<br>• Written exam, 90 min.<br><br>In the first lectures it will be announced whether the examination will be conducted in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Circuit Design”<br><br>If required, all concepts in the lectures of this module can also be explained in German. Please speak to the professor responsible. |
| **Module Components** | • Lecture: Antennas II<br>• Exercise to the lecture<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14318 Antenna Design Laboratory I

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14318 | Compulsory elective |

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|---|---|
| **Modul Title** | **Antenna Design Laboratory I**<br>Antennendesign Praktikum I |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr.-Ing. habil. Ndip, Ivan |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be able to model, simulate and analyze single elements of an antenna configuration using a 3D field solver, e.g. Ansys HFSS. They will also be able to create layouts of the antenna elements and perform S-parameter measurements. |
| **Contents** | • Basic concepts of antenna design<br>• Introduction to high-frequency modelling and simulation of antennas using 3D field solvers, e.g. Ansys HFSS<br>• Practical design and layout of an antenna element, selected from the antenna configurations in module “Antennas I” or module “Grundlagen der Antennen”<br>• Investigation of the impact of the geometrical parameters of the antenna elements and substrate materials on antenna characteristics using a 3D field solver<br>• S-parameter measurements<br>• Documentation of results |
| **Recommended Prerequisites** | Knowledge of the content of one of the following modules<br>• 14316 – *Antennas I*<br><br>OR<br>• 14315 – *Grundlagen der Antennen* |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Practical training - 4 hours per week per semester |

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| | Study project - 60 hours<br>Self organised studies - 60 hours |
| **Teaching Materials and Literature** | • Lecture notes<br>• Constantine A. Balanis: Antenna Theory, Analysis and Design, Wiley; 4th Edition, 2016<br>• Warren L. Stutzman, Gary A. Thiele: Antenna Theory and Design, Wiley; 3rd Edition, 2012 |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Practical design, approx. 10 pages (60%)<br>• Presentation with professional discussion, approx. 25 min. (40%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physik B.Sc.: Compulsory elective module in complex „Physikalisches Vertiefungsfach“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Circuit Design“<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Hardware-basierte Systeme“<br><br>If required, all concepts in the lectures of this module can also be explained in German. Please speak to the professor responsible. |
| **Module Components** | • Practical training: Antenna Design Laboratory I |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14319 Antenna Design Laboratory II

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14319 | Compulsory elective |

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|---|---|
| **Modul Title** | **Antenna Design Laboratory II**<br>Antennendesign Praktikum II |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr.-Ing. habil. Ndip, Ivan |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be able to model, simulate and analyze simple arrays of an antenna configuration using a 3D field solver (e.g. Ansys HFSS). They will also be able to create layouts of the antenna arrays and perform both S-parameter and radiation pattern measurements. |
| **Contents** | • Practical design and layout of an antenna array, selected from the antenna configurations in the module “Antennas II”.<br>• Investigation of the impact of the geometrical parameters of an antenna array and substrate materials on the characteristics of the array using a 3D field solver<br>• S-parameter and radiation pattern measurements<br>• Documentation of results |
| **Recommended Prerequisites** | Knowledge of the content of the following module:<br>• 14318 – *Antenna Design Laboratory I*<br>• 14317 – *Antennas II* |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Practical training - 4 hours per week per semester<br>Study project - 60 hours<br>Self organised studies - 60 hours |
| **Teaching Materials and Literature** | • Lecture notes<br>• Constantine A. Balanis: Antenna Theory, Analysis and Design, Wiley; 4th Edition, 2016 |

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| | • Warren L. Stutzman, Gary A. Thiele: Antenna Theory and Design, Wiley; 3rd Edition, 2012 |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Practical design, approx. 10 pages (60%)<br>• Presentation with professional discussion, approx. 25 min. (40%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Circuit Design”<br><br>This module can also be offered in German if required. Please speak to the professor responsible. |
| **Module Components** | • Practical training: Antenna Design Laboratory II |
| **Components to be offered in the Current Semester** | **112330** Practical training<br>Antenna Design Laboratory II - 4 Hours per Term |

# Module 14320 Signal/Power Integrity and Electromagnetic Compatibility

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14320 | Compulsory elective |

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|---|---|
| **Modul Title** | **Signal/Power Integrity and Electromagnetic Compatibility**<br>Signal-/Powerintegrität und Elektromagnetische Verträglichkeit |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Dr.-Ing. habil. Ndip, Ivan |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will be acquainted with a) root causes of signal integrity (SI), power integrity (PI) and electromagnetic compatibility (EMC) issues in electronic systems, b) basic electromagnetic field and circuit concepts for analysis of SI, PI and EMC issues, especially in electronic packaging for radio frequency (RF) and high-speed systems. |
| **Contents** | • Introduction to signal integrity (SI), power integrity (PI) and electromagnetic compatibility (EMC)<br>• Signal distribution networks (SDNs) and power delivery networks (PDNs) in electronic systems<br>• Role of electronic packaging and heterogeneous integration technologies on signal and power integrity (SIPI) and EMC<br>• Basic electromagnetic field and circuit theories for SIPI and EMC<br>• SI: Analysis of single-ended and differential signal paths of SDNs<br>• PI: Analysis of impedance, inductance and capacitance of PDNs<br>• EMC: Analysis of coupling and undesired radiation<br>• EMC & SIPI: Introduction to design methodologies for SIPI and EMC |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |

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| **Teaching Materials and Literature** | • Lecture notes<br><br>• Stephen H. Hall, Howard L. Heck: Advanced Signal Integrity for High-Speed Digital Designs, Wiley 2009<br>• Paul G. Huray: The Foundations of Signal Integrity, Wiley, 2009<br>• Clayton Paul: Introduction to Electromagnetic Compatibility, Wiley, 2006<br>• Larry D. Smith, Eric Bogatin: Principles of Power Integrity for PDN Design-Simplified: Robust and Cost Effective Design for High Speed Digital Products, Prentice Hall, 2017<br>• Madhavan Swaminathan, Ege Engin: Power Integrity Modeling and Design for Semiconductors and Systems, Prentice Hall, 2007 |
| **Module Examination** | Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | • Oral exam, 30-45 min. OR<br>• Written exam, 90 min.<br><br>In the first lectures it will be announced whether the examination will be conducted in written or oral form. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Circuit Design”<br><br>If required, all concepts in the lectures of this module can also be explained in German. Please speak to the professor responsible. |
| **Module Components** | • Lecture: Signal/Power Integrity and Electromagnetic Compatibility<br>• Exercise to the lecture<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14360 Parallel Computing

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14360 | Compulsory elective |

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|---|---|
| **Modul Title** | **Parallel Computing**<br>Parallel Rechnen |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr.-Ing. Egbers, Christoph |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the course, you should know the basic concepts of parallel computing concerning programming (software) and hardware architecture. You should be able to implement numerical simulations from Computational Physics, CFD, and Image Processing. The own notebook with SMP CPU, BTU computing devices with SMP CPUs, the massiv parallel computer cluster of the BTU, and the resources of the North German Supercomputing Alliance (Norddeutscher Verbund für Hoch- und Höchstleistungsrechnen – HLRN) can be used for this purpose. Sequential algorithms can be analyzed on their potential for parallelization. |
| **Contents** | Hardware for parallel computing from a notebook to a massive parallel cluster. (Processing concepts:<br>Pipelining, Functional Parallelism, Multithreading, Shared Memory, Distributed Memory, Memory access<br>concepts). Programming with OpenMP, MPI and use of parallized libraries (e.g. LAPACK). The basics of parallel programming will be instructed by means of generic examples. The participants will introduce examples of numerical simulations from their natural science or their engineering context and work on them in small groups. These examples will be analyzed on their potential for parallelization. |
| **Recommended Prerequisites** | • Initial experience in programming with C, C++ or Fortran |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester |

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| | Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Text books on OpenMP and MPI.<br>• Tutorials and manuals introducing Unix, OpenMP and MPI will be provided online. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • 2-3 successful programming exercises (50 %)<br>• intermediate and final presentation (approx. 15 min.) of results (25 %)<br>• documentation of results (source code and 3-5 pages of explanation) (25 %) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | VL, Ü Parallel Computing  Current Description |
| **Components to be offered in the Current Semester** | **350151** Lecture<br>Parallel Computing - 2 Hours per Term<br>**350152** Exercise<br>Parallel Computing - 2 Hours per Term |

# Module 14442 Radio Frequency Integrated Circuit Design Lab

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14442 | Compulsory elective |

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|---|---|
| **Modul Title** | **Radio Frequency Integrated Circuit Design Lab**<br>Praxisorientierter Entwurf von integrierten Hochfrequenz-ICs |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr.-Ing. Kahmen, Gerhard |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every summer semester |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students have an overview of radio frequency (RF) transceiver architectures, RF devices and active/passive microelectronic components. They are able to apply common software tools for the design, layout and verification based on a mixer circuit realized on an IHP high performance semiconductor technology. Students are able to go through the entire design cycle from specification, schematic entry, simulation, layout to validation of the tape-out capable design of an application specific integrated circuit (ASIC). |
| **Contents** | • Transceiver architectures and figures of merit<br>• Introduction into active and passive microelectronic devices<br>• RF-Mixer basics<br>• RF-Mixer topologies<br>• Introduction into Keysight ADS Design Framework<br>• ASIC schematic design<br>• Introduction into Cadence Virtuoso (layout / physical design)<br>• ASIC Layout design<br>• Introduction into 2.5D electromagnetic (EM) design<br>• Circuit optimization<br>• Design Rule Check (DRC)<br>• Layout vs. Schematic<br>• Virtual Tape Out |
| **Recommended Prerequisites** | • Knowledge of electrical engineering at a level corresponding to the first four semesters of a Bachelor’s degree in electrical engineering |

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| | • Knowledge of the functioning and topology of electronic components, such as content of module 12364 Elektronische Bauelemente und Grundschaltungen<br>• Basic knowledge of Analog circuit design, such content of module 33315 Analoge Schaltungen<br>• Knowledge of the content of the module 14030 Radio Frequency Application-Specific Integrated Circuit Design |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Study project - 30 hours<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • P.R. Gray, P.J. Hurst, S.H. Lewis, R.G. Meyer, „Analysis and Design of Analog Integrated Circuits“, John Whiley & Sons, 4th Edition, 2001<br>• S. Dimirijev, „Understanding Semiconductor Devices“, Oxford University Press, 2nd Edition<br>• S. Voinigescu, „High-Frequency Integrated Circuits“, Cambridge University Press, 2013<br>• J.D. Cressler, G. Niu, „Silicon-Germanium Heterojunction Bipolar Transistors“, Artech House, 2003<br>• B. Razavi, „Design of Analog CMOS Integrated Circuits“, Mc Graw Hill 2001<br><br>Teaching material will be provided before each lecture. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |
| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Preparation of a design review presentation, approx. 30 hours<br><br>**Final module examination:**<br>• Defence of the design (design review) during the examination<br>• Oral examination, approx. 45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 15 |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Informatik M.Sc.: Compulsory elective module in field of application „Maschinenbau/Elektrotechnik“<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Hardware-basierte Systeme“ |
| **Module Components** | • Lecture Radio Frequency Integrated Circuit Design Lab<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14446 Neuromorphic Engineering

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14446 | Compulsory elective |

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|---|---|
| **Modul Title** | **Neuromorphic Engineering**<br>Neuromorphe Technologie |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Wenger, Christian |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successfully completing the module, students will have understand the principles of biological computation. They will know how to implement them in hardware. They will have basic skills in applying neuromorphic engineering. |
| **Contents** | Neuromorphic computing is an approach which is inspired by the structure and function of human brains. Neuromorphic computers are based on Silicon devices which use physical artificial neurons and synapses to apply computations. In recent times, the term neuromorphic has been used to describe analog, digital, mixed-mode analog/digital VLSI, and software systems that implement models of neural systems. The implementation of neuromorphic computing on the hardware level can be realized by oxide-based resistive or ferro-electric memristors. The lecture presents the principles of biological computation and their implementation in hardware. Basic building blocks of neuromorphic technology are presented. The implications for the development of novel information processing technologies are outlined. |
| **Recommended Prerequisites** | • Basic knowledge in physics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Self organised studies - 150 hours |
| **Teaching Materials and Literature** | Will be announced in the first lecture. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |

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| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• active participation in the internship day at the IHP with lab report<br><br>**Final Module Examination:**<br>• Oral examination, 30-45 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | 40 |
| **Remarks** | • Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“<br>• Study programme Micro- and Nanoelectronics M.Sc.: Compulsory elective module in complex „Technology and Devices“ |
| **Module Components** | • Lecture: Neuromorphic Engineering<br>• Related examination |
| **Components to be offered in the Current Semester** | No assignment |

# Module 14450 Hardware/Software Codesign for Embedded Systems

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14450 | Compulsory elective |

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|---|---|
| **Modul Title** | **Hardware/Software Codesign for Embedded Systems**<br>Hardware/Software Codesign für eingebettete Systeme |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Dr.-Ing. habil. Herglotz, Christian Josef |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | On special announcement |
| **Credits** | 6 |
| **Learning Outcome** | After successful completion of the modul, students know the systematic design of embedded hardware / software systems from specification and synthesis. They can use methods and tools on real-life problems. They can also judge upon the capabilities and limits of specific design tools. |
| **Contents** | Phases of system design. Structures of embedded systems. Continuous and discrete models. Models for discrete systems, properties and limitations. Introduction to SystemC. ASIPs and ASSPs. HW / SW partitioning: Profiling, static estimation, HW-SW co-simulation. Application specific processor design and optimisation. Automatic HW / SW partitioning. Hardware synthesis from behavioural specifications. |
| **Recommended Prerequisites** | Basic knowledge in digital design, computer architecture and software-systems design technology. |
| **Mandatory Prerequisites** | no successful completion of the module 12406 Hardware / Software Codesign für eingebettete Systeme |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Practical training - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | Script and presentations available for downloading.<br>List of references is presented at the beginning of the course.<br>Problems for exercises and instructions for lab experiments can be downloaded. |
| **Module Examination** | Prerequisite + Final Module Examination (MAP) |

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| **Assessment Mode for Module Examination** | **Prerequisite:**<br>• Successful completion of exercises and presentation of results in course<br><br>**Final module examination:**<br>• Oral examination, 30 min. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Informatik M.Sc.: Compulsory elective module in complex „Angewandte und Technische Informatik“ (level 400)<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Hardware-basierte Systeme: Elektrotechnik, Informationstechnik und Sensorik“<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject“ |
| **Module Components** | • Lecture: Hardware/Software Codesign for Embedded Systems<br>• Accompanying laboratory<br>• Related examination |
| **Components to be offered in the Current Semester** | **120423** Examination<br>Hardware-Software Co-Design für eingebettete Systeme (Wiederholung) |

# Module 14641 Heterogeneous Catalysis

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14641 | Compulsory elective |

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|---|---|
| **Modul Title** | **Heterogeneous Catalysis**<br>Heterogene Katalyse |
| **Department** | Faculty 2 - Environment and Natural Sciences |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Klepel, Olaf |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 6 |
| **Learning Outcome** | After completing this module, students will be able to investigate the course of heterogeneously catalysed reactions by linking knowledge from inorganic, physical and organic chemistry. They will be able to describe the structure and mode of action of important catalyst systems and characterise important catalyst types. Through self-study of original scientific literature, students will be able to understand German and English texts and reflect on their content in the context of the lecture material. In addition, students will have acquired further personal skills relevant to their degree programme through communicative interaction in seminars. |
| **Contents** | Fundamentals of micro- and macrokinetics, synthesis and characterisation of solid catalysts (acid catalysts, metal catalysts, transition metal oxides, carbon materials) and mechanisms of associated catalysed reactions, fundamentals of electrocatalysis and heterogeneous photocatalysis |
| **Recommended Prerequisites** | fundamental knowledge in general, inorganic, physical chemistry and physics |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Seminar - 1 hours per week per semester<br>Self organised studies - 165 hours |
| **Teaching Materials and Literature** | • Video-based teaching material (asynchronous)<br>• Baerns, M.; Behr, A.; Brehm, A. et al.: Technische Chemie, Wiley-VCH, 2013. |

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| | • Reschetilowski, W.: Einführung in die Heterogene Katalyse, Springer 2015.<br>• Weitkamp J., Puppe, L.: Catalysis and Zeolites, Springer, 1999. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | 2 written exams, each 45 minutes, weighted 50% |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | Seminar, examination |
| **Components to be offered in the Current Semester** | **220582** Seminar<br>Heterogeneous Catalysis - 1 Hours per Term |

# Module 14726 Mathematical Optimization Techniques and Applications

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 14726 | Compulsory elective |

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|---|---|
| **Modul Title** | **Mathematical Optimization Techniques and Applications**<br>Mathematische Optimierungstechniken und Anwendungen |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Fügenschuh, Armin |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | Upon successful completion of the module, students will have acquired an understanding of core mathematical tools used in modern optimization. They will be able to identify optimization structures in real-world problems, formalize these problems in mathematical terms, and apply suitable algorithms to obtain and interpret solutions. |
| **Contents** | Foundations of optimization theory, global vs. local optimality, geometry of optimization, optimization for graph problems, fundamentals of linear programming, duality principles, advanced simplex methods, discrete optimization, interior point and ellipsoid methods, nonlinear optimization, applied modeling.<br>Emphasis is placed both on theoretical insights and algorithmic implementation. |
| **Recommended Prerequisites** | Knowledge of subject matters of the modules<br>• 11103: Analysis I<br>• 11104: Analysis II<br>• 11101: Lineare Algebra und analytische Geometrie I<br><br>or of the modules<br>• 11112: Mathematik IT-1 (Diskrete Mathematik)<br>• 11113: Mathematik IT-2 (Lineare Algebra)<br>• 11213: Mathematik IT-3 (Analysis) |
| **Mandatory Prerequisites** | • No successful participation in module 13862 Optimierung und Operations Research. |

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| **Forms of Teaching and Proportion** | Lecture - 4 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 90 hours |
| **Teaching Materials and Literature** | • V. Chvatal, Linear Programming, Bedford St Martins Pr 3PL, 2016<br>• R.J. Vanderbei: Linear Programming - Foundations and Extensions, 5th Edition, Springer, 2020 |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • 4 intermediate tests of 30 minutes each, written during the lecture period.<br><br>The best 3 count 1/3 each for the final grade. |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Angewandte Mathematik M.Sc.: Compulsory elective module in complex „Optimierung"<br>• Study programme Mathematics M.Sc.: Compulsory elective module in complex „Optimization"<br>• Study programme Mathematical Data Science M.Sc.: Compulsory elective module in complex „Advanced Mathematical Methods in Data Science"<br>• Study programme Artificial Intelligence Science M.Sc.: Compulsory elective module in complex „Advanced Methods"<br>• Study programme Künstliche Intelligenz Technologie M.Sc.: Compulsory elective module in complex „Software-basierte Systeme"<br>• Study programme Physics M.Sc.: Compulsory elective module in complex „Minor Subject" |
| **Module Components** | • Lecture: Optimization and Operations Research<br>• Accompanying exercise |
| **Components to be offered in the Current Semester** | **130710** Lecture<br>Mathematical Optimization Techniques and Applications - 4 Hours per Term<br>**130711** Exercise<br>Mathematical Optimization Techniques and Applications - 2 Hours per Term |

# Module 44108 Thermal Process Engineering and Equilibrium Thermodynamics

assign to: Minor Subject

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 44108 | Compulsory elective |

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|---|---|
| **Modul Title** | **Thermal Process Engineering and Equilibrium Thermodynamics**<br>Thermische Prozesse und Gleichgewichtsthermodynamik |
| **Department** | Faculty 3 - Mechanical Engineering, Electrical and Energy Systems |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Röntzsch, Lars |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every winter semester |
| **Credits** | 6 |
| **Learning Outcome** | The module provides knowledge about equilibrium thermodynamics and its important technical applications. Based on the fundamentals in thermodynamics of mixtures, the student will learn how to calculate phase equilibria of real multicomponent systems. Upon successful completion of this course, students will be able to calculate equilibrium processes as absorption and extraction. The apparatuses for this separation processes can be dimensioned. |
| **Contents** | • pvt behaviour of real fluids<br>• Characterization of mixtures<br>• State laws (virial equations, cubic state laws, generalized state laws)<br>• Activity coefficient models (Wilson, NRTL, UNIQUAC …)<br>• Steam/liquid, liquid/liquid, and solid liquid equilibriums<br>• Thermal separation: absorption |
| **Recommended Prerequisites** | Strongly recommended:<br>• Knowledge in mathematics<br>• Physics, thermodynamics<br>• Fundamentals in thermal process engineering |
| **Mandatory Prerequisites** | none |
| **Forms of Teaching and Proportion** | Lecture - 2 hours per week per semester<br>Exercise - 2 hours per week per semester<br>Self organised studies - 120 hours |
| **Teaching Materials and Literature** | • Lecture handouts, formulary, exercise materials available on Moodle |

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| | • Coulson, John M.: Coulson & Richardson's chemical engineering volume 2. Butterworth-Heinemann, Oxford 2002.<br>• Felder, Richard M.; Rousseau, Ronald: Elementary principles of chemical processes. Wiley, New York 2000.<br>• Reid, Robert; Prausnitz, John; Pohling, Bruce: The properties of gases and liquids. McGraw Hill, New York 1987.<br>• Seader, J. D.; Henley, E.J.: Separation Process Principles. Wiley-VCH, Chichester 2006.<br>• Hillert, Mats: Phase equilibria, phase diagrams and phase transformations. Cambridge Univ. Press, Cambridge 2008. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • 10 calculation exercises (50%),<br>• oral test, 30 min (50%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | none |
| **Module Components** | • Lecture Thermal Process Engineering and Equilibrium Thermodynamics<br>• Exercise Thermal Process Engineering and Equilibrium Thermodynamics |
| **Components to be offered in the Current Semester** | **320704** Lecture<br>Thermal Process Engineering and Equilibrium Thermodynamics - 2 Hours per Term<br>**320705** Exercise<br>Thermal Process Engineering and Equilibrium Thermodynamics - 2 Hours per Term<br>**320775** Examination<br>Thermal Process Engineering and Equilibrium Thermodynamics |

# Module 13008 Research Module II

assign to: Research Phase

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13008 | Mandatory |

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| **Modul Title** | **Research Module II**<br>Forschungsmodul II |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. habil. Seibold, Götz |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 30 |
| **Learning Outcome** | After participating in Research Module II, students have the ability to familiarize themselves with the diverse application and research-related fields of activity and special expertise, and to deal with the frequently changing tasks that they will encounter in their later professional lives. They are able to work in a team, have individual skills such as diligence, perseverance, time management and initiative and can hold a technical discussion within the context of international science. |
| **Contents** | Research module II consists of a project planning phase, a laboratory internship and a working group seminar. It is usually carried out in the same subject area in which the master's thesis is to be written.<br><br>By attending physics colloquia, they are expected to gain insight into interdisciplinary research topics.<br><br>Under the guidance of a supervisor, the students deal with a scientific question in this field. The supervisor is a university lecturer at the BTU or a scientist at a non-university institute. In the second case, the course director names a mentor from the physics department at the beginning of the module, who will be involved in the assessment.<br>Research module II can include participation in the DPG spring conference. |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | • At least 54 credit points from the specialization phase |

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| **Forms of Teaching and Proportion** | Seminar - 2 hours per week per semester<br>Practical training - 360 hours<br>Self organised studies - 510 hours |
| **Teaching Materials and Literature** | References will be provided by the supervisor. |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • Active Participation in three Physics Colloquia organized by the Institute of Physics (20 %)<br>• Report on the project planning phase and methodology, 10-20 pages (20 %)<br>• Oral presentation, approx. 30 minutes (60 %) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |
| **Remarks** | • Study programme Physics M.Sc.: Mandatory module<br><br>The self-study consists of Reading specialist literature<br>• Preparation of the presentation and reports<br>• Reworking seminars and lectures<br><br>In addition, students are recommended to participate in the workshop "On the way to success", in which they are prepared to develop their own, distinctive offer in order to position themselves successfully on the job market. |
| **Module Components** | • Working group Seminars<br>• Physics Colloquia |
| **Components to be offered in the Current Semester** | **150470** Seminar<br>Oberseminar Experimentalphysik und Funktionale Materialien - 2 Hours per Term<br>**150371** Oberseminar<br>Applied Spectroscopy - 2 Hours per Term |

# Module 13039 Master Thesis

assign to: Research Phase

## Study programme Physics

| Degree | Module Number | Module Form |
|---|---|---|
| Master of Science | 13039 | Mandatory |

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|---|---|
| **Modul Title** | **Master Thesis**<br>Master-Arbeit |
| **Department** | Faculty 1 - Mathematics, Computer Science, Physics, Electrical Engineering and Information Technology |
| **Responsible Staff Member** | Prof. Dr. rer. nat. Gorelova, Darya |
| **Language of Teaching / Examination** | English |
| **Duration** | 1 semester |
| **Frequency of Offer** | Every semester |
| **Credits** | 30 |
| **Learning Outcome** | After successfully completing the module, students have shown that they were able to learn, understand and elaborate on a problem from modern research under the guidance of their supervisor. They have developed individual abilities as self-efficacy, team work and communication, time management and persistence. |
| **Contents** | Elaboration of the subject of the Master Thesis. Written presentation of the results in a scientific accepted form. Elaboration of an oral presentation on the project of the thesis. |
| **Recommended Prerequisites** | none |
| **Mandatory Prerequisites** | • At least 84 credit points<br>• Module 13008 : Research Module II |
| **Forms of Teaching and Proportion** | Research paper/essay - 900 hours |
| **Teaching Materials and Literature** | Literature from the scientific field of the master thesis |
| **Module Examination** | Continuous Assessment (MCA) |
| **Assessment Mode for Module Examination** | • written master thesis, with grade, (75%)<br>• oral presentation (30 minutes), with subsequent discussion, with grade, (25%) |
| **Evaluation of Module Examination** | Performance Verification – graded |
| **Limited Number of Participants** | none |

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| **Remarks** | • Study programme Physics M.Sc.: Mandatory module<br><br>The period up to the submission of the written elaboration is 5 months (study regulations §8).<br>After approval by the examination board, the Master's thesis can be written in German in exceptional cases (PStO §8). |
| **Module Components** | • Consultations, according to agreement<br>• Oral presentation (colloquium) |
| **Components to be offered in the Current Semester** | No assignment |

## Erläuterungen

Das Modulhandbuch bildet als Teil der Prüfungsordnung die Rechtsgrundlage für ein ordnungsgemäßes Studium. Darüber hinaus soll es jedoch auch Orientierung bei der Gestaltung des Studiums geben.

Dieses Modulhandbuch wurde am 18. September 2026 automatisch für den Master (universitär)-Studiengang Physics (universitäres Profil), PO-Version 2021, aus dem Prüfungsverwaltungssystem auf Basis der Prüfungsordnung generiert. Es enthält alle zugeordneten Module einschließlich der ausführlichen Modulbeschreibungen mit Stand vom 18. September 2026. Neben der Zusammensetzung aller Veranstaltungen zu einem Modul wird zusätzlich das Veranstaltungsangebot für das jeweils aktuelle Semester gemäß dem Veranstaltungsverzeichnis der BTU ausgegeben.

The module catalogue is part of the examination regulation and as such establishes the legal basis for studies according to the rules. Furthermore, it should also give orientation for the organisation of the studies.

This module catalogue was generated automatically by the examination administration system on the base of the examination regulation on the 18 September 2026, for the Master (universitär) of Physics (research-oriented profile). The examination version is the 2021, Catalogue contains all allocated modules including the detailed module descriptions from 18 September 2026. Apart from the composition of all components of a module, the list of lectures, seminars and events for the current semester according to the catalogue of lectures of the BTU is displayed.