Friedrich-Alexander-Universität
Erlangen-Nürnberg

# Module description

for the degree programme

Bachelor of Science

Clean Energy Processes

(Prüfungsordnungsversion: 20212)

# Table of contents

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| 1 | **Module name**<br>92793 | **Active project** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung mit Übung: Active Project (2 SWS)<br>Seminar: Active Project - Seminar (3 SWS) | -<br>- |
| 3 | Lecturers | Prof. Dr. Katharina Herkendell | |

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| 4 | **Module coordinator** | Prof. Dr. Katharina Herkendell |
| 5 | **Contents** | • Introduction to typical clean energy processes<br>• Characterization and evaluation of corresponding raw materials and their properties<br>• Introduction of important mechanisms, requirements and technical realizations<br>• Selection of quantitative descriptions of clean energy production processes<br>• Presentation of current topics in the field of clean energy processes |
| 6 | **Learning objectives and skills** | Students who successfully participate in this module<br>• know typical clean energy processes and corresponding raw materials<br>• can characterize and evaluate these raw materials and the properties of products<br>• know the main mechanisms, processes and technical realizations<br>• recognize the connections between the contents of further lectures and the foundation for quantitative description of clean energy production processes<br>• are able to present and discuss a new topic in the field of clean energy processes |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 3 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Seminarleistung |
| 11 | **Grading procedure** | Seminarleistung (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | no Bibliography information available! |

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|---|---|---|---|
| 1 | **Module name**<br>1999 | **Bachelor's thesis** | **15 ECTS** |
| 2 | Courses / lectures | No courses / lectures available for this module! | |
| 3 | Lecturers | No lecturers available since there are no courses / lectures for this module! | |

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| 4 | **Module coordinator** | |
| 5 | **Contents** | Independent work on a scientific problem in the field of clean energy processes in one of the following fields:<br><br>• Energy technologies<br>• Energy systems<br>• Electrical energy engineering<br>• Materials science and engineering<br>• Process engineering<br><br>The topic of the Bachelor's thesis shall be allocated by a university lecturer from the Department of CBI at FAU. |
| 6 | **Learning objectives and skills** | Students<br><br>• are  able to work independently on a scientific problem from a selected area of the study field clean energy processes within a given time limit<br>• develop independent ideas and concepts to solve scientific problems<br>• deal with theories, terminologies, specifics, limitations and doctrines of the subject in an in-depth and critical way and reflect on them<br>• can apply and further develop suitable scientific methods largely independently - also in new and unfamiliar as well as interdisciplinary contexts - as well as present the results in a scientifically appropriate form.<br>• can present subject-related content clearly and appropriately to the target group, both orally and in writing, and argue the case for it<br>• expand their planning and structuring skills in the implementation of a thematic project. |
| 7 | **Prerequisites** | Admission requirements for the Bachelor thesis are the acquisition of at least 110 ECTS credits and the successful completion of the GOP (see ABMPO/TechFak). |

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| | | The Bachelor’s thesis shall be written in English (see section 42 FPO CEP). |
| 8 | **Integration in curriculum** | Semester: 0 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | schriftlich/mündlich (5 Monate) |
| 11 | **Grading procedure** | schriftlich/mündlich (100%) |
| 12 | **Module frequency** | no Module frequency information available! |
| 13 | **Resit examinations** | The exams of this moduls can only be resit once. |
| 14 | **Workload in clock hours** | Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt)<br>Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt) |
| 15 | **Module duration** | ?? Semester (keine Angaben zur Dauer des Moduls hinterlegt) |
| 16 | **Teaching and examination language** | Deutsch |
| 17 | **Bibliography** | no Bibliography information available! |

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| 1 | **Module name**<br>92771 | **Foundations of chemical reaction engineering** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Foundations of chemical reaction engineering (2 SWS)<br>Übung: Foundations of chemical reaction engineering (Excercises) (2 SWS) | 5 ECTS<br>- |
| 3 | Lecturers | Dr. Peter Schulz<br>Prof. Dr. Peter Wasserscheid<br>Arooj Ahmed<br>Christoph Regele | |

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| 4 | **Module coordinator** | Dr. Peter Schulz<br>Prof. Dr. Peter Wasserscheid |
| 5 | **Contents** | • Fundamentals of inorganic and organic chemistry<br>• Types and mechanisms of chemical reactions<br>• Chemical compounds for energy storage and conversion<br>• Stability of chemical compounds<br>• Chemical compounds for gas cleaning processes<br>• Heterogeneous catalysis<br>• Reduction and oxidation reactions<br>• Hydrogenation/Dehydrogenation reactions |
| 6 | **Learning objectives and skills** | Students who participate in this course will become familiar with the basic chemistry behind energy conversion and storage.<br><br>Students who successfully participate in this module can<br>• Understand the basic principles of chemical reactions<br>• Assign the energy storage feasibility of chemical compounds<br>• Analyze decomposition of chemical compounds<br>• Understand the molecular basis for gas capture and cleaning<br>• Describe the mechanisms of reduction and oxidation processes<br>• Understand and apply the fundamental principles of catalysis<br>• Describe the mechanisms of hydrogenation/dehydrogenation processes |
| 7 | **Prerequisites** | To succeed in this course students will need to apply earlier acquired knowledge from e.g. organic, inorganic and physical chemistry (high school level). Fundamental understanding of mathematics is required. Basic knowledge in thermodynamics is beneficial. |
| 8 | **Integration in curriculum** | Semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |

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| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | 1) Roussak O.V., Applied Chemistry: a textbook for engineers and technologists, Springer, 2013 link<br>2) Jeffrey Gaffney, Nancy Marley, 1st Edition, 2017, General Chemistry for Engineers<br>3) Jan Hoinkins, Chemie für Ingenieure (german)<br>4) Andreas Jess, Peter Wasserscheid, Chemical Technology: From Principles to Products, 2nd Edition, Wiley-VCH |

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|---|---|---|---|
| 1 | **Module name**<br>92776 | **Fundamentals of electrical engineering** | **5 ECTS** |
| 2 | Courses / lectures | Tutorium: Fundamentals of Electrical Engineering - Group Tutorials (2 SWS)<br>Vorlesung: Fundamentals of Electrical Engineering (2 SWS)<br>Übung: Fundamentals of Electrical Engineering - Exercises (2 SWS) | -<br>5 ECTS<br>- |
| 3 | Lecturers | Hans Rosenberger | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Ralf Müller |
| 5 | **Contents** | • Elektrostatisches Feld<br>• Stationäres elektrisches Strömungsfeld<br>• Gleichstromnetzwerke<br>• Stationäres Magnetfeld<br>• Zeitlich veränderliches elektromagnetisches Feld<br>• Zeitlich periodische Vorgänge<br>• Ausgleichsvorgänge<br>• Halbleiterbauelemente und ausgewählte Grundschaltungen<br><br>====<br><br>• Electrostatic field<br>• Stationary electric flow field<br>• Direct current networks<br>• Stationary magnetic field<br>• Time-varying electromagnetic field<br>• Time periodic processes<br>• Transient processes<br>• Semiconductor devices and selected basic circuits |
| 6 | **Learning objectives and skills** | • Die Studierenden erläutern die Grundkonzepte von elektrische Ladung und Ladungsverteilungen. Sie nutzen das Coulombsche Gesetz und analysieren die elektrische Feldstärke, berechnen das elektrostatisches Potential und die elektrische Spannung. Sie bestimmen die elektrische Flussdichte und wenden das Gaußsche Gesetz an. Die Studierenden beschreiben Randbedingungen der Feldgrößen und bestimmen den Einfluss von Materie im elektrostatischen Feld. Sie bestimmen die relevanten Größen an Kondensator und Kapazität und ermitteln den Energiegehalt des elektrischen Feldes.<br>• Die Studierenden erläutern die Begriffe Strom und Stromdichte, sie verwenden das Ohmsche Gesetz und erläutern das Verhalten an Grenzflächen. Sie ermitteln Energie und Leistung.<br>• Die Studierenden erläutern die Rolle von Spannungs- und Stromquellen in Gleichstromnetze. Mit Hilfe der Kirchhoffsche Gleichungen analysieren sie einfache Widerstandsnetzwerke, |

die Wechselwirkung zwischen Quelle und Verbraucher und allgemeine Netzwerke.

- Die Studierenden erklären die Begriffe Magnetfeld und Magnete. Sie berechnen die im Magnetfeld auf bewegte Ladungen wirkenden Kräfte und die magnetische Feldstärke durch Nutzung des Durchflutungsgesetzes. Die Studierenden erläutern die magnetischen Eigenschaften der Materie und das Verhalten der Feldgrößen an Grenzflächen. Sie ermitteln die Induktivität.
- Die Studierenden nutzen das Induktionsgesetz, bestimmen die Selbstinduktion, analysieren einfache Induktivitätsnetzwerke und ermitteln die Gegeninduktivität. Sie analysieren den Energieinhalt des magnetischen Feldes, wenden die Prinzipien der Bewegungsinduktion (Generatorprinzip) und der Ruheinduktion (Übertrager) an.
- Die Studierenden erläutern die Beziehungen zeitlich veränderlicher Ströme und Spannungen. Sie verwenden Methoden der komplexen Wechselstromrechnung um Wechselspannungen und Wechselströme zu ermitteln. Sie ermitteln und analysieren die Übertragungsfunktionen linearer zeitinvarianter Systeme. Sie analysieren Leistung und Energie in Wechselspannungsnetzen.
- Die Studierenden analysieren lineare, zeitinvariante Systeme sowie Signale in Zeit- und Frequenzbereich (Fourieranalyse). Dazu bestimmen und analysieren sie die Eigenfunktionen von LTI-Systemen und deren Übertragungsfunktionen und untersuchen Schaltungen aus LTI-Systemen.
- Die Studierenden erläutern die Grundlagen von Ausgleichsvorgängen in einfachen Netzwerken und berechnen diese bei der R-L-Reihenschaltung. Sie erläutern divergierende Fälle und untersuchen Netzwerke mit einem Energiespeicher mit Hilfe einer vereinfachten Analyse.
- Die Studierenden erläutern den Ladungstransport in Halbleitern und analysieren den pn-Übergang. Sie ermitteln Ströme und Spannungen bei den folgenden Halbleiterbauelementen: Halbleiterdiode, Z-Diode, Bipolartransistor, Feldeffekttransistor Thyristor, IG-Bipolar-Transistor.
- Die Studierenden wenden alle eingeführten Inhalte an, um selbständig einfache und dabei dennoch möglichst praxisnahe kleine Probleme systematisch zu lösen. Sie kontrollieren dabei selbst ihren Lernfortschritt und besprechen Fragen mit einem Tutoren, woraus sich Fachgespräche entwickeln, wie sie die ähnlich später in Verhandlungen und bei der Produktentwicklung mit Fachingenieurinnen und Fachingenieuren aus Elektro- und Informationstechnik führen müssen, sowie im interdisziplinären Dialog mit Elektro- und Informationstechnikern und Physikern.
- Die Studierenden erkennen die Vorzüge einer regelmäßigen Nachbereitung und Vertiefung des Stoffes, da sie in diesem

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| | | Modul ein für ihr Fachstudium fremdes Gebiet kennenlernen mit einer teilweise anderen mathematischen und physikalischen Herangehensweise. Sie zeigen eine hohe Arbeitsdisziplin, Freude am Entdecken von Neuem, aber auch eine gewisse Belastbarkeit und Leistungsbereitschaft.<br><br>====<br>• Students explain the basic concepts of electric charge and charge distributions. They use Coulomb's law and analyze the electric field strength, calculate the electrostatic potential and the electric voltage. They determine electric flux density and apply Gauss's law. Students describe boundary conditions of field quantities and determine the influence of matter in the electrostatic field. They determine the relevant quantities at the capacitor and capacitance and determine the energy content of the electric field.<br>• The students explain the terms current and current density, they use Ohm's law and explain the behavior at boundaries. They determine energy and power.<br>• Students explain the role of voltage and current sources in DC power systems. Using Kirchhoff's equations, they analyze simple resistor networks, the interaction between source and load, and general networks.<br>• Students explain the terms magnetic field and magnets. They calculate the<br>• forces acting on moving charges in the magnetic field and the magnetic field strength by using the law of flux. Students explain the magnetic properties of matter and the behavior of field quantities at boundaries. They determine inductance.<br>• Students use the law of induction, determine self-inductance, analyze simple inductance networks, and determine mutual inductance. They analyze the energy content of the magnetic field, apply the principles of motion induction (generator principle) and rest induction (transformer).<br>• Students explain the relationships of time-varying currents and voltages. They use methods of complex numbers in AC curcuits to determine alternating voltages and alternating currents. They determine and analyze the transfer functions of linear time-invariant systems. They analyze power and energy in AC power systems.<br>• Students analyze linear, time-invariant systems as well as signals in time and frequency domain (Fourier analysis). For this purpose, they determine and analyze the eigenfunctions of LTI systems and their transfer functions and examine circuits from LTI systems. |

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| | | • The students explain the basics of transient processes in simple networks and calculate them for the R-L series circuit. They explain divergent cases and investigate networks with an energy storage using a simplified analysis.<br>• Students explain charge transport in semiconductors and analyze the pn junction. They determine currents and voltages for the following semiconductor devices: Semiconductor diode, Z-diode, bipolar transistor, field effect transistor thyristor, IG bipolar transistor.<br>• The students apply all introduced contents to independently and systematically solve simple and yet practical small problems. They control their learning progress themselves and discuss questions with a tutor, from which technical discussions develop, as they later have to conduct them similarly in negotiations and product development with specialist engineers from electrical and information engineering, as well as in interdisciplinary dialog with electrical and information engineers and physicists.<br>• Students recognize the benefits of regular follow-up and consolidation of the material, since in this module they become acquainted with an area that is unfamiliar to their specialized studies, with a partially different mathematical and physical approach. They show a high level of work discipline, enjoy discovering new things, but also a certain resilience and willingness to perform. |
| 7 | **Prerequisites** | The students use methods of vector analysis and use Cartesian coordinates, cylindrical and polar coordinates. They solve systems of linear equations and calculate with complex numbers. They use the trigonometric formulas and solve linear ordinary differential equations with constant coefficients in transient processes. Students know and understand basic physical concepts, especially quantities and quantity equations. |
| 8 | **Integration in curriculum** | Semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Sommersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • Manuskript zur Vorlesung / Lecture notes<br>• ALBACH, M.: Elektrotechnik, 1. Auflage, Pearson-Studium, München, 2011.<br>• ALBACH, M., FISCHER, J.: Übungsbuch Elektrotechnik, 1. Auflage, Pearson-Studium, München, 2012. |

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| | | • FROHNE, H. et al.: Moeller Grundlagen der Elektrotechnik, 22., verbesserte Auflage, Vieweg+Teubner Verlag, Wiesbaden, 2011.<br>• SPECOVIUS, J.: Grundkurs Leistungselektronik: Bauelemente, Schaltungen und Systeme , 4. Auflage, Vieweg+Teubner, Wiesbaden, 2010. |

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| 1 | **Module name**<br>92773 | **Interface engineering and particle technology** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Interface Engineering and Particle Technology (2 SWS)<br>Übung: Exercise Interface Engineering and Particle Technology (3 SWS) | 5 ECTS<br>- |
| 3 | Lecturers | Prof. Dr. Robin Klupp Taylor | |

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| 4 | **Module coordinator** | Prof. Dr. Robin Klupp Taylor |
| 5 | **Contents** | This module provides students with an overview of the following key concepts and practical aspects of the fields of interfacial engineering and particle technology:<br>• Molecular interactions: Adsorption and adhesion<br>• Particle nucleation and growth<br>• Particle stabilization<br>• Particle size and shape.<br>• Particles in motion<br>• Particle size distributions<br>• Unit operations: separations, mixing, comminution<br>• Packed and fluidized beds<br><br>The associated exercises and homework cover all topics and allow students to develop their understanding independently with follow-up support from the course tutors. |
| 6 | **Learning objectives and skills** | Students who successfully participate in this module can<br>• understand the relevance of interfaces in the natural and artificial world.<br>• master the fundamentals of the subject and apply them to the specific case of wetting, particle nucleation, growth and stabilization<br>• analyse interfacial-dependent processes in their connection with engineering challenges and develop solutions.<br>• define the societal relevance of particle technology<br>• give examples of unit operations of particle technology<br>• differentiate between the various approaches for defining particle size and shape<br>• analyze the motion of particles according to physical and engineering principles<br>• analyze particle size distributions, distinguish between accepted norms for their presentation, and apply them for the analysis of separation equipment<br>• describe the structure of packings and bulk materials and the perfusion of those<br>• describe the fundamentals of the processes of separation, mixing, comminution and fluidization<br>• apply their acquired knowledge and skills in the additional exercises and tutorials in order to solve independently problems from interfacial and mechanical processes engineering |

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| 7 | **Prerequisites** | To succeed in this course, students will need to apply acquired knowledge from e.g. physics, physical chemistry and mathematics. |
| 8 | **Integration in curriculum** | Semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Sommersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | Unless stated, online texts are only available within the FAU network (or remotely via VPN)<br>Interface Engineering<br><br>• Adamson, A.W. and Gast, A.P. (1997) Physical chemistry of surfaces, 6th edn, Wiley, New York, Chichester. FAU library holdings<br>• Berti, D. and Palazzo, G. (2014) Colloidal foundations of nanoscience, Elsevier, Amsterdam. Full Text<br>• Butt, H.-J.B., Graf, K., Kappl, M. (2003) Physics and chemistry of interfaces, Wiley-VCH; Chichester : John Wiley, Weinheim. Full Text<br>• Cosgrove, T. (2005) Colloid science: Principles, methods and applications / edited by Terence Cosgrove, Blackwell Pub, Oxford, Ames, Iowa. Full Text<br>• Everett, D.H. (2007) Basic principles of colloid science, Royal Society of Chemistry, London.  Full Text<br>• Israelachvili, J.N. (2012) Intermolecular and surface forces, 3rd edn, Academic Press is an imprint of Elsevier, Amsterdam. Full Text<br>• Kontogeorgis, G.M. and Kiil, S. (2016) Introduction to applied colloid and surface chemistry, Wiley, Chichester, UK. Full Text<br>• Lyklema, J. (2005) Fundamentals of interface and colloid science. Elsevier/Academic Press, Amsterdam, London. Full Text<br>• Mersmann, A. (2001) Crystallization Technology Handbook, CRC Press, Boca Raton FAU library holdings<br>• Stokes, R.J. and Evans, D.F. (1997) Fundamentals of interfacial engineering, Wiley-VCH, New York, Chichester. FAU library holdings<br>• Tadros, T.F. (2012) Dispersion of powders in liquids and stabilization of suspensions, Wiley-VCH, Weinheim, Germany. Full Text<br>• Tadros, T.F. (2015) Interfacial phenomena and colloid stability, De Gruyter, Berlin. Full Text<br>• Tadros, T.F. (2018) Formulation science and technology, De Gruyter, Berlin. Full Text |

-
  - Volume 1 - Basic Theory of Interfacial Phenomena and Colloid Stability Full Text
  - Volume 2 - Basic Principles of Dispersions Full Text
  - Volume 3 - Industrial Applications I - Pharmaceuticals, Cosmetics and Personal Care Full Text
  - Volume 4 - Industrial Applications II - Agrochemicals, Paints, Coatings and Food Systems Full Text

Particle Technology
Peukert, W.: Lecture Script - available as copy-protected online viewable document or in printed form, obtainable for free on showing your FAU ID card at CopyArenA, Karlsbader Str. 13 (N.B. some chapters are not covered in the IEPT module)

German Books

- Bohnet, M. (2012) Mechanische Verfahrenstechnik, John Wiley & Sons, Hoboken. Full text
- Löffler, F. and Raasch, J. (1992) Grundlagen der mechanischen Verfahrenstechnik, Vieweg, Braunschweig, Wiesbaden. FAU library holdings
- Müller, W. (2014) Mechanische Verfahrenstechnik und Ihre Gesetzmässigkeiten, 2nd edn, De Gruyter Oldenbourg.Full text
- Rumpf, H. (1975) Mechanische Verfahrenstechnik, 3rd edn, Carl Hanser Verlag, S.l. FAU library holdings
- Schubert, H. (2008) Handbuch der mechanischen Verfahrenstechnik, 1st edn, Wiley-VCH, Weinheim. Full text
- Schulze, D. (2014) Pulver und Schüttgüter: Fließeigenschaften und Handhabung, 3rd edn, Springer Vieweg, Berlin. Full text
- Stiess, M. (2009) Mechanische verfahrenstechnik - Partikeltechnologie 1, 3rd edn, Springer, Berlin. Full text
- Zogg, M. (1993) Einführung in die mechanische Verfahrenstechnik, 3rd edn, B.G. Teubner, Stuttgart. Full text (free)

English Books

- Allen, T. (ed) (2003) Powder Sampling and Particle Size Determination, Elsevier, Amsterdam. Full text
- Fayed, M.E. and Otten, L. (1997) Handbook of powder science & technology, 2nd edn, Chapman & Hall, New York, London. FAU library holdings
- Higashitani, K., Makino, H., Matsusaka, S. (2019) Powder technology handbook, CRC Press, Boca Raton. Full text
- Kaye, B.H. (1999) Characterization of powders and aerosols, Wiley-VCH, Weinheim, Chichester. Full text

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| | | • Ortega-Rivas, E. (2012) Unit Operations of Particulate Solids, CRC Press, Boca Raton. Full text<br>• Richardson, J.F., Harker, J.H., Backhurst, J.R. (eds) (2013) Coulson and Richardson's Chemical Engineering. Volume 2, Particle Technology and Separation Processes: Solutions to the problems in Chemical engineering, Butterworth-Heinemann, Oxford. Full text<br>• Rhodes, M.J. (2008) Introduction to Particle Technology, 2nd edn, Wiley, Chichester, UK. Full text<br>• Rumpf, H. (1990) Particle Technology, Chapman and Hall, London. FAU library holdings<br>• Seville, J. and Wu, C.-Y. (eds) (2016) Particle Technology and Engineering, Elsevier. Full text<br>• Svarovsky, L. (2001) Solid-Liquid Separation, 4th edn, Elsevier, Burlington. Full text |

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| 1 | **Module name**<br>92775 | **Materials and structure** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung mit Übung: Materials and Structure (CEP) (2 SWS) | 2 ECTS |
| 3 | Lecturers | Dr. Johannes Will<br>Prof. Dr. Erdmann Spiecker | |

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| 4 | **Module coordinator** | Prof. Dr. Erdmann Spiecker |
| 5 | **Contents** | The content of the module gives an overview of different fields of materials science and engineering. The following topics are included in the module:<br>• Atomic structure and interatomic bonding<br>• Structure of crystalline solids<br>• Structure determination by X-ray diffraction<br>• Imperfections in solids<br>• Microscopic characterization of crystal defects<br>• Mechanical properties of metals<br>• Dislocations and strengthening mechanisms<br>• Phase diagrams of binary alloys<br>• Phase diagrams of metals: development of microstructure<br>• Kinetics of phase transformations<br>• Structure and properties of ceramics<br><br>The lecture, which includes exercises, is accompanied by a seminar, in which the students prepare contributions about specific aspects in the framework of the above mentioned topics. |
| 6 | **Learning objectives and skills** | Students who participate in this course will become familiar with basic, important concepts of materials and their structure.<br><br><br>The course enables the students:<br>•<br>• to classify different types of bonding that occur in materials<br>• to understand the relationship between bonding, structure and fundamental materials properties<br>• to describe crystalline materials with basic concepts of crystallography<br>• to classify crystal defects with respect to their dimensionality<br>• to describe the importance of dislocations and interfaces for the mechanical properties of metals<br>• to understand the development of microstructure based on phase diagrams and the kinetics of phase transformation<br>• to describe basic crystal structures of ceramics<br>• to prepare and give a talk in a scientific environment |
| 7 | **Prerequisites** | Prerequisites: |

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| | | Basics of chemistry and maths |
| 8 | **Integration in curriculum** | Semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Sommersemester |
| 13 | **Workload in clock hours** | Contact hours: 50 h<br>Independent study: 100 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • William D. Callister, Jr., "Materials Science and Engineering: An Introduction", John Wiley & Sons, Inc., 7th edition (or later) |

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| 1 | **Module name**<br>62765 | **Mathematics I** | **7,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Mathematics for Engineers I (4 SWS)<br>Übung: Exercise Mathematics for Engineers I (2 SWS) | -<br>- |
| 3 | Lecturers | Dr. Yasmine Sanderson | |

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| 4 | **Module coordinator** | apl.Prof.Dr. Wilhelm Merz |
| 5 | **Contents** | • Foundations:<br>• logic, sets, relations, mappings<br>• Number systems:<br>• natural numbers; integers; rational, real and complex numbers<br>• Vector spaces:<br>• Foundations, linear dependence, span, basis, dimension, Euclidean vector space, subspaces, affince spaces<br>• Matrices, linear maps, systems of linear equations:<br>• Matrix algebra, structure of the solution sets of linear equations, Gauss algorithm, inverse matrix, types of matrices, linear maps, determinants, image and kernel, eigenvalues and eigenvectors, basis, least squares problems<br>• Foundations of real analysis:<br>• limits, continuity, elementary functions, inverse functions |
| 6 | **Learning objectives and skills** | Students learn:<br>• fundamental terms and structures of mathematics<br>• structure of the number system<br>• certain handling of vectores and matrices<br>• solution techniques for linear systems of equations<br>• fundamentals of analysis and exact mathematical analytical methods |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 90 h<br>Independent study: 135 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2013.<br>• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2014. |

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| 1 | **Module name**<br>62767 | **Mathematics II** | **7,5 ECTS** |
| 2 | Courses / lectures | No courses / lectures available for this module! | |
| 3 | Lecturers | No lecturers available since there are no courses / lectures for this module! | |

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| 4 | **Module coordinator** | apl.Prof.Dr. Wilhelm Merz |
| 5 | **Contents** | • Calculus for functions of one real variable:<br>• derivative with rules, mean value theorems, L'Hospital, Taylor's theorem, curve discussion<br>• Integrals for functions of one real variable:<br>• Riemann-Integral, Fundamental Theorem of Calculus, mean value theorems, improper integrals<br>• Sequences and series:<br>• real and complex sequences of numbers, convergence: definition and theorems, sequences and series of functions, uniform convergence, power series, Fourier series, iterative solution of nonlinear equations<br>• Foundations of calculus for functions of several real variables:<br>• limit, continuity, differentiation, partial derivative, total derivative, Taylor's theorem |
| 6 | **Learning objectives and skills** | Students learn:<br>• skilful handling of differential and integral calculus<br>• handling of mathematical models<br>• convergence of sequences and series<br>• computing of limits<br>• basic properties of multidimensional functions |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%)<br>• |
| 12 | **Module frequency** | nur im Sommersemester |
| 13 | **Workload in clock hours** | Contact hours: 90 h<br>Independent study: 135 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2013.<br>• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2014.<br>• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Analysis in #^n und |

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| | | gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017.<br>• W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Analysis in #^2^ und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017. |

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| 1 | **Module name**<br>62769 | **Mathematics III** | **7,5 ECTS** |
| 2 | Courses / lectures | Übung: Exercise Mathematics for Engineers III (0 SWS)<br>Vorlesung: Mathematics for Engineers III (4 SWS) | -<br>- |
| 3 | Lecturers | apl.Prof.Dr. Wilhelm Merz | |

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| 4 | **Module coordinator** | apl.Prof.Dr. Wilhelm Merz |
| 5 | **Contents** | • Application of calculus in IR^n:<br>• Unconstrained optimization problems; constrained optimization problems; Lagrange multiplie rules; implicit function theorem; examples of applications;<br>• Vector analysis:<br>• Potential, volume integrals, surface integrals, line integrals, parametrization, transformation theorem, integral theorems, differential operators,<br>• Ordinary differential equations:<br>• analytical solution methods; existence and uniqueness of solutions; linear differential equations; systems of differential equations; eigenvalues of differential operators; generalized eigenvectors; fundamental systems; stability |
| 6 | **Learning objectives and skills** | Students learn:<br>• extreme value determination in higher dimensions<br>• identify significant differences compared to one dimensional optimization techniques<br>• relationship between volume, surface and line integrals<br>• knowledge of various differential operators<br>• typing of ordinary differential equations<br>• fundamental solution techniques<br>• applications in engineering science |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 3 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 90 h<br>Independent study: 135 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in R. 1. Aufl., Berlin Heidelberg: Springer, 2013.<br>• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in R. 1. Aufl., Berlin Heidelberg: Springer, 2014.<br>• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Analysis in R und |

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| | | gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017.<br>• W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Analysis in R^n und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017. |

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| 1 | **Module name**<br>92778 | **Measurement systems** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung mit Übung: Measurement Systems (2 SWS)<br>Seminar: Measurement Systems (Sem) (2 SWS) | 5 ECTS<br>5 ECTS |
| 3 | Lecturers | Prof. Dr. Robin Klupp Taylor | |

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| 4 | **Module coordinator** | Prof. Dr. Robin Klupp Taylor |
| 5 | **Contents** | • Introduction and basic concepts<br>• Data evaluation and measurement errors<br>• Estimates, statistical tests and confidence intervals<br>• Chemical analysis<br>• Radiation measurement<br>• Spectrometry<br>• Electrical and magnetic sizes<br>• Temperature<br>• Pressure<br>• Mechanical and geometric sizes<br>• Fluid systems |
| 6 | **Learning objectives and skills** | On completion of the module Students will be able to<br>• Identify and explain the most important methods of electrical and non-electrical measurement as well as chemical analysis<br>• Assess different approaches to measurement in terms of their advantages and disadvantages<br>• Apply the fundamental criteria for the assessment of measurements to new analytical scenarios |
| 7 | **Prerequisites** | To succeed in this course, students will need to apply acquired knowledge from e.g. physics, physical chemistry and mathematics. |
| 8 | **Integration in curriculum** | Semester: 3 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • Patience, G.S. (2018) Experimental methods and instrumentation for chemical engineers, Elsevier, Amsterdam.<br>• Morris, A.S. and Langari, R. (2016) Measurement and instrumentation: Theory and application, Elsevier, AP, Amsterdam, Boston.<br>• Jones, E.B. and Noltingk, B.E. (1985-) Jones' Instrument technology, 4th edn, Butterworths, London, Boston |

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| 1 | **Module name**<br>87007 | **Microeconomics** | **5 ECTS** |
| 2 | Courses / lectures | Übung: Microeconomics (IES/IBS) Exercise (2 SWS)<br>Vorlesung: Microeconomics (2 SWS) | 5 ECTS<br>5 ECTS |
| 3 | Lecturers | Yuval Ofek-Shanny<br>Prof. Dr. Veronika Grimm | |

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| 4 | **Module coordinator** | Nima Farhang-Damghani<br>Prof. Dr. Veronika Grimm<br>Simon Mehl |
| 5 | **Contents** | Microeconomics is an undergraduate course that introduces basic microeconomic concepts. The course opens with a general introduction to the field of Economics. The main topics of the course include: Choice under constraints, in strategic interaction, within the firm, under different institutions. The Firm production, price-setting, price-taking. The Market market equilibrium, market failures. If time permits, Environmental Economics will conclude the semester as an application of the models studied.<br><br>The learning methodology of the course is to start from a question that arises from data or daily life, then study a model useful for answering the question and back to question at the end to apply the model we studied. |
| 6 | **Learning objectives and skills** | The students will acquire the ability to -<br><br>define the core concepts of microeconomics,<br><br>describe some historical background of Economics science development,<br><br>use models and data to analyze an economic question or phenomenon,<br><br>fit a proper model to an economic issue,<br><br>investigate a current microeconomic issue. |
| 7 | **Prerequisites** | none |
| 8 | **Integration in curriculum** | Semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | The CORE Team, The Economy: Economics for a changing world. (2017). The CORE Team, Economy, Society, and Public Policy, (2019) |

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| 1 | **Module name**<br>62766 | **Physics I** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Physics I (Clean Energy Processes) (3 SWS)<br>Übung: Physics I (Clean Energy Processes, Exercise Class) (2 SWS) | -<br>- |
| 3 | Lecturers | Prof. Dr. Christopher van Eldik | |

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| 4 | **Module coordinator** | Prof. Dr. Christopher van Eldik |
| 5 | **Contents** | **Mechanics:**<br>• Measurements, units, dimensions, magnitudes<br>• Motion in one spatial dimension<br>• Motion in three spatial dimensions<br>• Newton's laws and concept of forces<br>• Work, energy, power<br>• Centre of gravity, momentum, impact processes<br>• Rotational motion<br>• Law of gravity<br>• Mechanics of deformable bodies, liquids, gases<br><br>**Oscillations and waves:**<br><br>• Undamped, damped and forced oscillations<br>• Superposition<br>• Wave propagation<br>• Diffraction<br>• Geometrical optics<br><br>**Thermodynamics:**<br><br>• Temperature, ideal gas<br>• Kinetic theory of gases<br>• Real gas, phase diagram<br>• Heat capacity, melting, evaporation energy<br>• Thermal conductivity, thermal radiation<br>• Heat engines, conversion efficiency |
| 6 | **Learning objectives and skills** | The students<br>• can explain basics of mechanics and thermodynamics<br>• have a basic understanding of how natural processes can be traced back to fundamental natural laws<br>• apply the acquired knowledge to special situations and questions in mechanics and thermodynamics<br>• have basic competence in analytical thinking as a means of describing scientific relationships accurately |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |

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| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | no Bibliography information available! |

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| 1 | **Module name**<br>62768 | **Physics II** | **5 ECTS** |
| 2 | Courses / lectures | No courses / lectures available for this module! | |
| 3 | Lecturers | No lecturers available since there are no courses / lectures for this module! | |

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| 4 | **Module coordinator** | Prof. Dr. Christopher van Eldik |
| 5 | **Contents** | **Electrodynamics:**<br>• Electrostatics<br>• Electrical current, voltage, resistance<br>• Magnetostatics<br>• Electrodynamics<br><br>**Modern Physics:**<br><br>• Quantum properties of light<br>• Quantum mechanics<br>• Atomic physics<br>• Solid state physics<br>• Nuclear and particle physics |
| 6 | **Learning objectives and skills** | The students<br>• can explain basics of electrodynamics and modern physics<br>• have a basic understanding of how natural processes can be traced back to fundamental natural laws<br>• apply the acquired knowledge to special situations and questions in electrodynamics and modern physics<br>• have basic competence in analytical thinking as a means of describing scientific relationships accurately |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Sommersemester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | no Bibliography information available! |

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| 1 | **Module name**<br>92772 | **Renewable energies** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Renewable Energies (2 SWS)<br>Übung: Renewable Energies (tutorial) (2 SWS) | -<br>- |
| 3 | Lecturers | Prof. Dr. Katharina Herkendell | |

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| 4 | **Module coordinator** | Prof. Dr. Katharina Herkendell |
| 5 | **Contents** | • Climate change and energy transition<br>• Renewable electricity generation and transmission<br>• Wind energy<br>• Photovoltaics<br>• Bioenergy<br>• Geothermal energy<br>• Hydropower<br>• Heat and electricity storage<br>• Sector coupling and system integration |
| 6 | **Learning objectives and skills** | Students who participate in this course will become familiar with basic concepts of conventional energies.<br><br>Students who successfully participate in this module will<br>• know the fundamentals of renewable energy conversion processes<br>• assess environmental and social aspects of renewable energy conversion. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | Semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 45 h<br>Independent study: 105 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • Slides published via StudOn<br>• Karl; Dezentrale Energiesysteme; Oldenbourg-Verlag<br>• Sterner, Stadler; Energiespeicher - Bedarf, Technologien, Integration; Springer Verlag<br>• Quaschning; Regenerative Energiesysteme: Technologie - Berechnung Simulation; Carl Hanser Verlag |

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| 1 | **Module name**<br>92777 | **Thermodynamics and heat and mass transfer** | **7,5 ECTS** |
| 2 | Courses / lectures | Übung: Exercise in Thermodynamics and Heat and Mass Transfer (2 SWS)<br>Vorlesung: Thermodynamics and Heat and Mass Transfer (4 SWS) | 2,5 ECTS<br>5 ECTS |
| 3 | Lecturers | Tobias Klein<br>Dr.-Ing. Michael Rausch<br>Prof. Dr.-Ing. Andreas Paul Fröba | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andreas Paul Fröba |
| 5 | **Contents** | THERMODYNAMICS<br>• Basics of Engineering Thermodynamics<br>• Ideal Gas and Equations of States<br>• First and Second Law of Thermodynamics<br>• Efficiency Limits of Energy Conversion<br>• Thermodynamic Properties of Pure Substances (and Mixtures)<br>• Cycles (Power Cycle, Heat Pump, Refrigerator)<br>• Mixtures of Ideal Gases and of Air and Steam<br>• Processes with Humid Air<br><br>HEAT & MASS TRANSFER<br><br>• Basics of Heat & Mass Transfer<br>• Steady and Transient Heat Conduction and Mass Diffusion<br>• Natural Convection / Forced Convection Heat & Mass Transfer<br>• Radiation Heat Transfer<br>• Condensation and Evaporation Heat Transfer<br>• Heat Exchangers |
| 6 | **Learning objectives and skills** | Students who successfully participate in this module will<br>• become familiar with the basics of engineering thermodynamics<br>• establish energy and exergy balances<br>• apply thermodynamic methodology for the calculation/ description of properties of state as well as changes of state of pure fluids<br>• analyze important thermodynamic processes on the basis of key figures<br>• design and optimize thermodynamic processes<br>• solve fundamental problems related to themodynamics<br>• become familiar with the basics of heat and mass transfer<br>• understand the mechanisms of heat and mass transfer and assess/evaluate their individual contributions in technical problems<br>• quantify different heat transfer mechanisms (heat conduction, convection, radiation, and two phase heat transfer)<br>• perform independently the thermal design of simple heat exchangers<br>• understand the analogy between heat and mass transfer and apply it to solving problems of mass transfer |

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| | | • solve fundamental problems related to heat and mass transfer |
| 7 | **Prerequisites** | Prerequisites:<br><br>Basics of mathematics (total differential, differential equations, differential operators). Basic knowledge in physics. |
| 8 | **Integration in curriculum** | Semester: 3 |
| 9 | **Module compatibility** | Pflichtmodul Bachelor of Science Clean Energy Processes 20212 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | nur im Wintersemester |
| 13 | **Workload in clock hours** | Contact hours: 90 h<br>Independent study: 135 h |
| 14 | **Module duration** | 1 Semester |
| 15 | **Teaching and examination language** | Englisch |
| 16 | **Bibliography** | • Lecture Notes<br>• Y. A. Çengel, R. H. Turner, and J. M. Cimbala, Fundamentals of Thermal-Fluid Sciences, McGraw-Hill 2017 (5th edition)<br>• J. M. Smith, H. C. Van Ness und M. M. Abbott, Introduction to Chemical Engineering Thermodynamics, McGraw-Hill 2005 (7th edition)<br>• A. Bejan, Advanced Engineering Thermodynamics, John Wiley & Sons 2016 (4th edition)<br>• H. D. Baehr and K. Stephan, Heat and Mass Transfer, Springer 2011 (3rd edition) |