Module Descriptions

Master of Science Energy Science and Technology

Examination Regulations in the Version of: 2013
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# Chemistry I
Modules referring to Chemistry

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<td>Duration</td>
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<td>Cycle</td>
<td>each Winter Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr. R. J. Behm, Faculty of Natural Sciences</td>
</tr>
</tbody>
</table>
| Instructor(s)         | Prof. Dr. R. J. Behm, Prof. Dr. Thorsten Bernhardt, Prof. Dr. J. Bansmann, Faculty of Natural Sciences  
                        | Prof. Dr. U. Herr, Prof. Dr. H. Kabza, Faculty of Engineering and Computer Science |
| Allocation of study programmes | First semester MSc Energy Science and Technology |
| Recommended prerequisites | Parallel attendance of Introductory Chemistry for students with a Bachelor of Engineering or a non-chemistry background |
| Learning objectives   | Physical Chemistry  
                        | Students should be able to  
                        | • apply the laws and principles of thermodynamics and of reaction kinetics when analyzing chemical reactions with respect to energy conversion, equilibrium and reaction rate.  
                        | • describe the influence of external parameters on chemical reactions.  
                        | • describe atomic structures and the formation of bonds between atoms in terms of quantum mechanics.  
                        | • understand and describe the principles of selected spectroscopy techniques in Chemistry, and interpret simple spectra.  
                        | Introductory Laboratory  
                        | Students should be able to  
                        | • apply scientific principles introduced in the courses Physical Chemistry, Energy Science and Technology I and Materials Science I to analyze the properties of chemical reactions and compounds.  
                        | • set up and carry out an advanced scientific experiment. |
document the data and write a lab report.

**Syllabus**

**Physical Chemistry**

- Thermodynamics: The laws of thermodynamics, enthalpy, entropy, free-energy, absolute zero of temperature, applications to chemical reactions, chemical equilibrium.
- Reaction kinetics: reaction rate / rate equation, reaction order, dependence of reaction rate on temperature, activation energy, catalysis
- Quantum Chemistry: Properties of waves and the wave-nature of matter, atomic structure and orbital theory, atomic orbitals (hydrogen atom) and molecular orbitals, principles of chemical bond formation.
- Spectroscopy: Basic spectroscopy techniques in Chemistry

**Introductory Laboratory:**

- DC-Laboratory
- AC-Laboratory
- Machine Lab
- Thermodynamics: Determination of enthalpy and entropy for evaporation of liquid dichloromethane (application of Clausius-Clapeyron Equation).
- Reaction kinetics: Saponification of a carboxylic acid ester in alkaline surrounding; determination of activation energy and of the order of the reaction.
- Combustion /Calorimetry: Determination of the energy of combustion of an organic compound using a bomb calorimeter.
- X-ray Diffraction: Analysis of atomic or molecular structure of crystalline and polycrystalline substances by X-Ray Diffraction; powder diffraction, grain size analysis.
- X-ray Fluorescence

**Literature**

**Physical Chemistry:**


**Introductory Laboratory:**

Handouts

**Teaching and learning methods**

**Physical Chemistry**

- 4 credit points
- Lecture 2 h/week
- Problem solving 1h/week

**Introductory Laboratory**

- 5 credit points
- 5 h/week

**Workload**

**Physical Chemistry:** Total: 120 h

- Lecture: 32 h presence
  34 h preparation and post processing
- Problem solving: 16 h presence
  24 h preparation and post processing
Exam: 14 h preparation

Introductory Laboratory: Total: 150 h

80 h presence
16 h preparation
54 h revision, writing reports

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**Assessment**

Module description will be available shortly.

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**Grading procedure**

Module description will be available shortly.

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**Basis for**

Module *Chemistry II*
# Chemistry II

Modules referring to Chemistry

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<td>Coordinator</td>
<td>Prof. Dr. R. J. Behm, Faculty of Natural Sciences</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr. R. J. Behm, Prof. Dr. M. Fichtner, Dr. E. Mena-Osteritz, Faculty of Natural Sciences</td>
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<tr>
<td>Allocation of study programmes</td>
<td>Second semester MSc Energy Science and Technology</td>
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<td>Module Chemistry I</td>
</tr>
<tr>
<td>Learning objectives</td>
<td>Surfaces – Interfaces – Heterogeneous Catalysis – Electrocatalysis</td>
</tr>
</tbody>
</table>

**Students should be able to**

- describe basic aspects of solid surfaces and their properties (structure, electronic properties) as well as their interaction with adsorbates;
- describe basic principles of heterogeneous catalysis and catalytic reactions, and apply them to model reactions (CO oxidation and ammonia synthesis);
- explain fundamental principles of electrochemistry, including solid electrolyte interface, potentials, electrode kinetics, transport effects, understand basic electrochemical measurements .
- describe basic principles, energetics and kinetics of electrocatalytic reactions, focusing on fuel cell relevant reactions, and predict simple trends for suitable catalysts

**Materials Chemistry**

**Students should be able to**

- **a) Chemistry of Inorganic Solids:**
  - describe the structure, bonding and the electronic structure of an inorganic solid
• decide which method of characterization can be applied for different inorganic solid materials
• describe basic synthetic methods for the fabrication of inorganic materials
• correlate the electrical, optical and magnetic properties of the material with its nanostructure, defect structure

b) Organic Materials
• describe the fundamentals in organic materials formation
• represent and understand the different classes of organic materials
• describe the application’s spectrum in material chemistry

Syllabus
Surfaces – Interfaces – Heterogeneous Catalysis – Electrocatalysis

• Surfaces: Phenomenologic thermodynamics of surfaces, surface structure and electronic properties of solid surfaces, interaction of molecules with surfaces (thermodynamics, kinetics and energetics);
• Catalytic Surface Reaction (Heterogeneous Catalysis): Fundamental aspects, methodical approach, basic reaction types, activity, selectivity, electronic and structural effects, Sabatier principle, Bronstedt-Evans-Polanyi principle, model reactions (CO oxidation, ammonia synthesis);
• Electrochemistry: Galvanic cells, potentials in electrochemistry, standard electrode potential, electrochemical double layer, electrode kinetics, transport effects, experimental methods;
• Electrocatalysis: General aspects, influence of the electric potential on energetics and kinetics of electrocatalytic reactions, kinetic / transport limitations in electrocatalytic reactions, internal resistance effects, examples of electrocatalytic reactions, temperature effects.

Materials Chemistry

1. Solid State Chemistry and its application to energy materials:
• States of matter, classification of solids, forces in solids, challenges of energy materials
• Methods for syntheses and modification of solids: sintering, mechanochemical synthesis, transport reaction, Reaction in melts, precursor method, hydrothermal method, sol-gel method, wet chemical synthesis (precipitation of nanoparticles), chemical vapour deposition (CVD), physical vapour deposition (PVD), doping and intercalation
• Structure: Close packing, basic structure types, ionic crystals, basic structure types, complex structures, Hume Rothery phases, Laves phases, Zintl phases, defect chemistry, nanochemistry
• Solid state phenomena and their characterization: solid state thermodynamics and kinetics (equilibria, state functions, thermodynamics of H storage materials and of batteries, rate laws, energetic barriers, kinetic modeling of solid state reactions), surface analysis (SIMS, XPS, AES), thermal properties (heat capacity, thermal conductivity, phase changes and thermal decomposition, methods: DSC, DTA, TGA, MS)
• Discussion of selected examples of energy materials: synthesis, characterization, properties, optimization

2. Organic materials:
• Structure: chemical structure of organic oligo- and polymers.
• Material formation: intermolecular interactions, introduction in supramolecular chemistry
• Classes of organic materials: dyes, polymers, conductive oligo- and polymers.
• Structure-property relationship of organic materials
<table>
<thead>
<tr>
<th>Literature</th>
<th>Surfaces – Interfaces – Heterogeneous Catalysis – Electrocatalysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Somorjai, G.A.: Introduction to Surface Chemistry (Wiley – VCh, Weinheim, 2000)</td>
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<td>Materials Chemistry</td>
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<table>
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<tr>
<th>Teaching and learning methods</th>
<th>Surfaces – Interfaces – Heterogeneous Catalysis – Electrocatalysis</th>
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<tr>
<td></td>
<td>5 credit points</td>
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<td>Lecture 3h/week</td>
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<td>Seminar 1h/week</td>
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<td>Materials Chemistry</td>
<td>4 credit points</td>
</tr>
<tr>
<td></td>
<td>Lecture 3 h/week</td>
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</table>

| Workload                     | Surfaces – Interfaces – Heterogeneous Catalysis – Electrocatalysis: |
|------------------------------|Total 150 h |
|                              | 56 h lecture and seminar (presence) |
|                              | 78 h preparation and revision of lecture and seminar and solving of problems |
|                              | 16 h preparation for exam |
| Materials Chemistry          | Total 120 h |
|                              | 42 h lecture (presence) |
|                              | 62 h preparation and revision lecture |
|                              | 16 h exam preparation |

| Assessment                   | Module description will be available shortly. |
| Grading procedure            | Module description will be available shortly. |
| Basis for                    | Module *Energy Science and Technology III-Electrochemical EST* |
|                              | Elective Course *Polymeric Materials* |
**Electrical Engineering**

Modules referring to Electrical Engineering

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<tr>
<td>Coordinator</td>
<td>Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science</td>
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**Allocation of study programmes**

- First semester MSc *Energy Science and Technology*
- First semester MSc *Advanced Materials*, focus Nanomaterials

**Recommended prerequisites**

- Fundamentals of mathematics and physics
- Course *Introductory Electrical Engineering*

**Learning objectives**

Students should be able to

- perform circuit analysis of linear DC and AC (RLC) circuits.
- explain the basics of semiconductor physics.
- explain how basic semiconductor devices work.
- handle and evaluate measured data on a basic level.
- convert analogue data into digital data.
- handle digital data.
- specify advantages and problems of digital data processing.

**Syllabus**

- Circuit analysis: Network analysis, Thevenin and Norton equivalent circuits, superposition principle, linearity, capacitors & inductors, transformers
- Analysis of transients: Frequency analysis, filters etc.: Frequency response, logarithmic scale, Bode diagram, low pass, high pass, 2nd order low pass etc.
- Fourier and Laplace transformation: Transfer function, step, pulse response, convolution
- Semiconductors: Band structure, density of states, Fermi statistics, impurity conduction, mobility, diffusion, Hall effect
- Diodes: p-n-junction, load line analysis, pn as capacitance, Schottky diode
• Transistors: Bipolar transistor (band structure, common base, common emitter, amplification), Field Effect Transistor (Structure, operation, enhancement and depletion); load line analysis
• Devices for measurement: Operational amplifier, basics, adder, subtractor, integrator, differentiator, logarithmiser
• Probability distribution functions: Binomial, Poisson, Gauss
• Signal filtering, noise: Thermal, shot, 1/f, distribution, generation-recombination,
• Digital Signal Processing: basic logic operations, adders, flip-flop, Digitization: Basics, sampling theorem, DA and AD converters, Digital filters, z-transformation

Literature

Teaching and learning methods
5 credit points
Lecture 3 h/week
Solving problems 1 h/week

Workload
Total: 150 h
Lecture: 48 h presence
44 h preparation and revision
Solving problems: 16 h presence
28 h revision
Exam preparation 14 h exam

Assessment
not specified

Grading procedure
not specified

Basis for
Modules Materials Science II, Nanomaterials II
Elective courses
# Materials Science

Modules referring to Materials Science

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr. U. Herr, Faculty of Engineering and Computer Science</td>
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<tr>
<td>Instructor(s)</td>
<td>Prof. Dr. U. Herr and lecturers of the Faculty of Engineering and Computer Science</td>
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**Allocation of study programmes**
First and second semester MSc Energy Science and Technology

**Recommended prerequisites**
Fundamentals of mathematics, physics and chemistry

**Learning objectives**
Materials Science I
Students should be able to
- classify metallic, ceramic and polymeric materials based on their structure on the atomic scale, microstructure and macroscopic properties.
- analyze different materials with respect to mechanical strength.
- understand the physical basis for thermal, electrical and magnetic properties of solid materials.

Materials Science II
Students should be able to
- interpret the influence of the processing of a metallic alloy, ceramic and polymeric substance on its microstructure and properties.
- relate the structure of a composite material to improved strength and toughness.
- select appropriate materials and processing routes for the realization of an engineering design goal, based on properties and performance characteristics.
Materials Science I

- Classification of materials with respect to chemical bond and structure.
- Crystal structure: Symmetry classes, lattices, reciprocal lattice, diffraction.
- Defects in solids: Point defects, dislocations, grain and phase boundaries.
- Characterization of the microstructure: Microscopic methods (optical, SEM), diffraction techniques (XRD, TEM), scanning probe techniques (introduction).
- Phase diagrams: Thermodynamics of solutions, chemical potential, phase equilibrium, basic types of phase diagrams, important examples.
- Transport: Diffusion (macroscopic and microscopic description), diffusion at surfaces and interfaces, electromigration, thermotransport.
- Phase transformations: Thermodynamics and kinetics, diffusive transformations, non-diffusive transformations.
- Mechanical properties: Elasticity, plastic deformation, viscous flow and creep, fracture.

Materials Science II

- Application of basic concepts introduced in part I of the lecture to different classes of materials: Metallic alloys, ceramics, glasses, polymers.
- Processing/optimization of materials, heat treatment
- Electrical properties of materials
- Semiconductors
- Magnetic properties of materials
- Optical properties of materials

Literature


Teaching and learning methods

Materials Science I
- 5 credit points
- Lecture 3 h/week
- Solving problems 1 h/week

Materials Science II
- 5 credit points
- Lecture 3 h/week
- Exercise 1 h/week

Workload

Materials Science I:
- Total 150 h
- Lecture: 48 h lecture (presence)
- 38 h preparation and revision
- Solving problems: 16 h presence
- 32 h revision
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<tr>
<td>Exam</td>
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<td>Materials Science II:</td>
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<td>Total 150 h</td>
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<td>Lecture</td>
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<td>50 h preparation and revision</td>
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<td>Solving problems:</td>
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<td>28 h revision, solution of exercises</td>
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<tr>
<td>Exam</td>
<td>16 h preparation</td>
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**Assessment**

Derzeit steht keine deutsche Modulbeschreibung zur Verfügung.

**Grading procedure**

Weighted average of graded exams according to credit points

**Basis for**

Module *Energy Science and Technology III-Electrochemical EST MSc Energy Science and Technology*
Energy Science and Technology I - General Aspects
Modules referring to Energy Science and Technology

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<td>First and second semester MSc Energy Science and Technology</td>
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<tr>
<td>Recommended prerequisites</td>
<td>Module Engineering</td>
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<td>Course Energy Science and Technology II is based on course Energy Science and Technology I</td>
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<td>Learning objectives</td>
<td>Energy Science and Technology I</td>
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<tr>
<td>Students should be able to</td>
<td></td>
</tr>
<tr>
<td>• comprehend the background and basic facts, components, and interactions in the field of energy technology.</td>
<td></td>
</tr>
<tr>
<td>• understand and explain the basic physical principles underlying mechanical-electrical energy conversion.</td>
<td></td>
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<tr>
<td>• describe the structure and functional mechanisms of the basic types of electric machines (DC separately excited, parallel and series wound; asynchronous; synchronous), and sketch their equivalent circuits as well as torque-speed characteristics.</td>
<td></td>
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<tr>
<td>• solve simple problems related to the interrelations between voltage, current, power and torque in the different types of electric machines.</td>
<td></td>
</tr>
<tr>
<td>• describe the structure of the electric grid with its various voltage levels and name its basic components.</td>
<td></td>
</tr>
<tr>
<td>• describe the functional mechanisms of the different thermal power plants (gas turbines, steam process) and explain the basic components.</td>
<td></td>
</tr>
<tr>
<td>• solve simple problems in the field of technical thermodynamics.</td>
<td></td>
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<tr>
<td>• describe the functional mechanisms of hydro and wind power plants as well as explain the main components (such as e.g. types of water turbines) and their application.</td>
<td></td>
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<tr>
<td>• solve simple problems in the field of hydro and wind power applications.</td>
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</table>
Energy Science and Technology II

Students should be able to

• understand and explain the construction and functional mechanisms of hydro-, wind-, solar thermal- and photovoltaic power plants of different kinds and describe and explain their components.

• perform base calculations for the design, for the dimensioning of component parameters and for the operation of such power plants.

• explain the balance terms “cumulated energy input, energy gain ratio, energy pay-back time” and use them for approximative calculations.

• distinguish the different kinds of potentials in the use of regenerative sources with different technologies and give approximative quantities for them.

• to reproduce approximative quantities of real use and perform elementary calculations in these fields.

• describe and explain the reasons for limitations in the use of regenerative sources.

• understand the technical possibilities for long-distance energy imports from regenerative sources and can point out the necessary effort and cost.

• describe possible storage technologies together with their problems.

• understand and describe structure and functional mechanisms in cogeneration as well as absorption cooling technologies together with their advantages/disadvantages.

Syllabus

Energy Science and Technology I

The course gives an overview on conventional (electric) power technology:

• Development and status of energy consumption and resources; its limitations and consequences

• Physical basics of mechanical – electrical energy conversion

• Types of electric machines: DC separately excited, parallel and series wound; asynchronous; synchronous, special forms like AC machines, linear drives, electronically commutated machines; their construction, function, characteristics and applications

• Structure and function of the electric power grid and its components

• Electric power generation by means of thermal power plants and their thermodynamic fundamentals: Entropy, Carnot -, (Joule) Brayton - and (Clausius) Rankine - cycle

• Nuclear power plants, nuclear fusion technology

• Electric power generation from renewable sources: Hydro and wind power, photovoltaics, further technologies in the field of renewables

Energy Science and Technology II

The course gives an overview on technologies using renewable sources and the concepts of distributed power technologies. At the center of the course is a comparison of various technologies to produce electricity or thermal energy for room heating and warm water production in terms of

• primary energy input

• energy pay-back time and energy gain ratios

• consumption of materials, resources and area

• ecological impact

• economy and cost

To do so the physical fundamentals, the peculiarities and the degree of usage as well as the potential for use of the following technologies are discussed in detail:

• hydro power
• wind power
• photovoltaics
• low-temperature solar thermal power
• high-temperature thermal solar power for electricity generation and thermal processing

Further topics:

• Possibilities and implications of renewable energy imports over long distances like e.g. from North Africa to Europe
• Necessities for storage technologies and the problems associated
• Cogeneration concepts and absorption cooling

Literature

Energy Science and Technology I

• Lecture manuscript, materials on E-learning platform ILIAS.
• Any physics textbook on magnetics.

Energy Science and Technology II

• Lecture manuscript, materials on E-learning platform (ILIAS).
• Distributed Generation in Liberalised Electricity Markets; OECD/IEA 2002.
• Kaltmann , Martin (Ed.): Renewable energy technology, economics and environment. Springer, Berlin, Heidelberg u. a., 2007.
### Teaching and learning methods

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
<th>Lecture</th>
<th>Tutorial</th>
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<tr>
<td>Energy Science and Technology I</td>
<td>5</td>
<td>3 h/week</td>
<td>1 h/week</td>
</tr>
<tr>
<td>Energy Science and Technology II</td>
<td>5</td>
<td>3 h/week</td>
<td>1 h/week</td>
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### Workload

**Energy Science and Technology I:**
- **Total 150 h**
- **Lecture:**
  - 48 h presence
  - 48 h preparation and revision
- **Tutorial:**
  - 16 h presence
  - 22 h solving problems, revision
- **Exam:**
  - 16 h preparation

**Energy Science and Technology II:**
- **Total 150 h**
- **Lecture:**
  - 42 h presence
  - 42 h preparation and revision
- **Tutorial:**
  - 14 h presence
  - 36 h solving problems, revision
- **Exam:**
  - 16 h preparation

### Assessment

Module description will be available shortly.

### Grading procedure

Module description will be available shortly.

### Basis for

Module *Energy Science and Technology II-Applications*
# Energy Science and Technology II - Applications

Modules referring to Energy Science and Technology

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<tr>
<td>Duration</td>
<td>2 Semester Semester</td>
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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr. J. Kallo, Faculty of Engineering, Computer Science and Psychology</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr. R.J. Behm, Prof. Dr. A. Latz, Prof. M. Fichtner, Prof Dr. W. Tillmetz, Dr. R. Zeis, Faculty of Natural Sciences Prof. Dr. U. Herr, Prof. Dr. J. Kallo, Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science</td>
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<tr>
<td>Allocation of study programmes</td>
<td>Second and third semester of MSc Energy Science and Technology</td>
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<tr>
<td>Recommended prerequisites</td>
<td>Module Engineering Module Energy Science and Technology I – General Aspects</td>
</tr>
<tr>
<td>Learning objectives</td>
<td>Students should be able to</td>
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<tr>
<td></td>
<td>• integrate scientific principles of energy conversion and catalysis, knowledge about properties of the materials employed and engineering aspects of energy usage, conversion and storage and apply this to practical application</td>
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<tr>
<td></td>
<td>• conduct advanced experiments and write corresponding reports</td>
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<tr>
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<td>• prepare and give a presentation on a topic in the field of energy science and technology based on literature and internet research</td>
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<tr>
<td>Syllabus</td>
<td>Energy Technology Lab I</td>
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<tr>
<td></td>
<td>• Solar cells</td>
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<tr>
<td></td>
<td>• DC / DC Converter</td>
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<tr>
<td></td>
<td>• CHP system (combined heat and power)</td>
</tr>
<tr>
<td></td>
<td>• H2 – storage</td>
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<td></td>
<td>• Lambda Probe</td>
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<td>• Impedance Spectroscopy</td>
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<td>• Heterogeneous Catalysis - CO oxidation</td>
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<td>• Electrocatalysis – Methanol electrooxidation</td>
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<tr>
<td></td>
<td>• Electrocatalysis – Fuel Cell</td>
</tr>
</tbody>
</table>
Seminar Energy Science and Technology

- Current topics in the field of Energy Science and Technology
- Supervised preparation of student presentation
- Presentation and discussion in the seminar

**Literature**

Check references for module *Energy Science and Technology I – General Aspects*

**Teaching and learning methods**

Energy Technology Lab I

Second semester, 9 credit points
Preparation of experiments (self-study + colloquium), experiments, presentations, writing reports

Seminar EST

Third semester, 2 credit points
Preparation of presentations, presentations, discussion in the seminar

**Workload**

Energy Technology Lab: Total 270 h
126 h presence in lab and accompanying seminar
144 h preparation, writing reports, presentation

Seminar Energy Science and Technology: Total 60 h
32 h presence
28 h preparation, search of literature, preparation of presentation and handout

**Assessment**

Module description will be available shortly.

**Grading procedure**

Module description will be available shortly.

**Basis for**

Master Thesis
# Energy Science and Technology III - Electrochemical EST

Modules referring to Energy Science and Technology

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<td>Duration</td>
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<td>Cycle</td>
<td>each Winter Semester</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr. W. Tillmetz, Faculty of Natural Sciences, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg</td>
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<tr>
<td>Instructor(s)</td>
<td>Prof. Dr. W. Tillmetz, Faculty of Natural Sciences, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg</td>
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<tr>
<td>Allocation of study programmes</td>
<td>Third semester MSc Energy Science and Technology</td>
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<tr>
<td>Recommended prerequisites</td>
<td>Modules Chemistry I and Chemistry II Module Engineering</td>
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</table>
| Learning objectives | The students should be able to
| Syllabus       | Energy Science and Technology III
1) Fuel cells
   • Types, components, operational characteristics, degradation
   • Catalysts, electrodes, bipolar plates, electrolytes,
   • Test of performance
   • Applications: Automobiles, buses, stationary CHP and back-up power, leisure market

1) Batteries:
   • Rechargeable batteries and electrochemical double layer capacitors: types, characteristics, charge, discharge, degradation
   • Electrolytes and electrodes, design principles
• Battery systems, battery management, thermal management, maintenance, safety

Energy Technology Lab II

• I/U characteristics of electrolyzer and fuel cell single cells
• Characteristics of a fuel cell system; hydrogen powered operational features of a fuel cell system combined with a battery (hybrid)
• Characteristics of a fuel cell test bench: Flow and pressure control, temperature and humidity control, sensors and data recording
• Operation of commercial fuel cell products: DMFC for remote power and onboard power supply; Hydrogen Fuel Cell System for Back Up and Emergency Power Supply
• Characteristics of lead acid and alkaline batteries, electrochemical double layer capacitors, (charge/discharge behavior)

Literature


Teaching and learning methods

Energy Science and Technology III
5 credit points
Lecture 3 h/week
Solving problems 1 h/week

Energy Technology Laboratory II
4 credit points
4 h/week

Workload

Energy Science and Technology III:
Total 150 h
Lecture: 48 h presence
50 h preparation and revision
Solving problems: 16 h presence
20 h solving problems, revision
Exam: 16 h preparation

Energy Technology Laboratory II:
Total 120 h
64 h experiments in lab (presence)
16 h preparation of experiments
40 h writing of lab reports

Assessment

Module description will be available shortly.

Grading procedure

Module description will be available shortly.
Energy Science and Technology IV - Simulation and Modeling

Modules referring to Energy Science and Technology

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<td>Coordinator</td>
<td>Prof. Dr. A. Latz, Faculty of Natural Sciences, Helmholtz Institute Ulm</td>
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<td>Prof. Dr. A. Latz, Faculty of Natural Sciences, Helmholtz Institute Ulm</td>
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Allocation of study programmes
Third Semester MSc Energy Science and Technology

Recommended prerequisites

Learning objectives
Student will be able to

• understand the basic theoretical concepts of electrochemistry, non-equilibrium thermodynamics and chemical kinetics
• distinguish between the modeling approaches for different length and time scales
• perform discretization of transport equations using Finite difference, Finite Volume and Finite Element Techniques
• solve numerically ordinary and partial differential equations using standard software tools
• describe mathematically the operation of batteries and fuel cells

Syllabus

• Transport theory
• Thermodynamics and chemical kinetics of electrochemical systems
• Introduction to simulation techniques
• Discretization of transport equations and kinetic equations
• Fundamentals of systems theory
• Modelling of Batteries
• Modelling of fuel cells
• Software exercises
**Literature**


**Teaching and learning methods**

Lecture, 2 h/week

Solving problems, 2 h/week

**Workload**

Total: 150 h

Lecture: 32 h presence

50 h revision

Solving problems: 32 h presence

36 h preparation and revision

**Assessment**

Module description will be available shortly.

**Grading procedure**

Module description will be available shortly.

**Basis for**

Master thesis
Compulsory Elective Module Introductory Chemistry
Modules referring to Compulsory Elective Module Chemistry or Electrical Engineering

Code 8833271944

ECTS credits 3

Attendance time 2

Language of instruction English

Duration 1 Semester Semester

Cycle each Winter Semester

Coordinator Prof. Dr. M. Fichtner, Faculty of Natural Sciences

Instructor(s) Prof. Dr. M. Fichtner, Faculty of Natural Sciences

Allocation of study programmes First semester MSc Energy Science and Technology

Recommended prerequisites Bachelor degree
Fundamentals in mathematics, physics and chemistry

Learning objectives Students should be able to
• discuss a given chemical element with respect to its position in the periodic table of elements, structure of its electron shell and its ability to form chemical bonds
• describe the equilibrium of a given reaction according to the mass action law
• use the idea of the pH-value and the acid/base-pK_a/pK_b-value to analyze the properties of water, oxo-acids, week acids and bases, buffers and indicators
• identify a redox reaction and analyze it with respect to the redox potential of the individual reactants and the difference in redox potential of the overall reaction

Syllabus
• Structure of matter, states of matter, phase diagrams, separation techniques
• Atom structure (qualitative): Bohr's atom model, hydrogen atom, isotopes, periodic table of the elements
• Formation of chemical bonds, bond order, molecular orbital
• Chemical bonding: Compounds with covalent bonds, inorganic salts, van der Waals forces, Metals/semiconductors
• Chemical reaction: Reaction equilibrium, mass action law, principle of LeChatelier
• Water: Structure and properties, pH-value
• Acids and bases: theories, pK_a and pK_b-values, oxo-acids, weak acids and bases, buffers, indicators, titrations
• Redox-reactions: Oxidation, reduction, oxidation numbers, redox potential, Nernst’s equation,
• Selected large scale reactions
• Organic chemistry nomenclature, functional groups, principle reactions

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<td>Module Chemistry I</td>
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Compulsory Elective Module Introductory Electrical Engineering

Modules referring to Compulsory Elective Module Chemistry or Electrical Engineering

Code 8833271945

ECTS credits 3

Attendance time 2

Language of instruction English

Duration 1 Semester Semester

Cycle each Winter Semester

Coordinator Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science

Instructor(s) Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science

Allocation of study programmes First semester MSc Energy Science and Technology

Recommended prerequisites Bachelor degree
Fundamentals in mathematics, physics and chemistry

Learning objectives Students should be able to
• explain voltage-current relations of basic circuit elements
• analyze transient problems of RLC circuits
• evaluate measured data in terms of value and accuracy
• transform decimal into binary numbers
• analyze simple logic gate arrays

Syllabus
• Measurement units, SI units
• Basic circuit elements (voltage source, current source, resistance, capacitance, inductance, impedance)
• Kirchhoff's laws
• Analysis of transients: First and second order transient circuits, respective linear differential equations
• Basics of measurement, errors, statistics: Random and systematic errors, mean value, standard deviation
• Basics of Digital Signal Processing: Binary numbers, basic logic operations
|---------------------|----------------------------------------------------------------------------------|
| **Teaching and learning methods** | 3 credit points  
Lecture, 2 h/week |
| **Workload**        | Total 90 h  
32 h attendance  
44 h preparation and revision  
14 h exam preparation |
| **Assessment**      | Module description will be available shortly. |
| **Grading procedure** | Module description will be available shortly. |
| **Basis for**       | Module Engineering |

Master of Science Energy Science and Technology  
Date printed: 17. Februar 2017  
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## Elective Courses - Energy Science and Technology

### Modules referring to Elective Modules

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<td><strong>Coordinator</strong></td>
<td>Prof. Dr. R. J. Behm, Faculty of Natural Science</td>
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</table>
| **Instructor(s)**     | Prof. Dr. S. Altmann, BASF Ludwigshafen  
*Innovation Management for Nanotechnology*  
Prof. Dr. C. Mohrdieck, Daimler AG, Kirchheim-Teck, Nabern  
*Hydrogen as Energy Carrier*  
Prof. Dr. W. Münch, EnBW, Karlsruhe  
*Scientific, Economical and Ecological Aspects of the Energy Economy*  
Dr. M. Wohlfahrt-Mehrens, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)  
*Lithium Ion Batteries*  
Dr. R. Zeis, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)  
*Characterization Techniques for Fuel Cells and Batteries*  
Prof. Dr. U. Ziener, Faculty of Natural Sciences  
*Polymeric Materials* |

### Allocation of study programmes

Second and third semester *Energy Science and Technology*

### Recommended prerequisites

Depending on the course:  
Module *Energy Science and Technology I-General Aspects*  
Module *Energy Science and Technology I-Applications*  
Module *Energy Science and Technology III- Electrochemical Energy Science and Technology*

### Learning objectives

Innovation Management for Nanotechnology (Altmann)  
Students should be able to
• analyze and discuss the linkage between fundamental science, technology push and market demand in the field of nanotechnology.

Hydrogen as Energy Carrier (Mohrdieck)

Students should be able to
• describe and analyze scientific, technological and economic aspects of hydrogen usage.
• discuss future potentials of hydrogen usage.

Scientific, Economical and Ecological aspects of the Energy Economy (Münch)

Students should be able to
• describe the German energy system
• analyze the interdependency of economy and ecology

Lithium Ion Batteries (Wohlfahrt-Mehrens)

Students should be able to
• understand the general parameters of Lithium ion batteries
• interpret performance data sheets of batteries and to select a suitable battery for a given application profile
• calculate specific capacity, energy density and voltage profile from thermodynamic data
• to calculate the amount of reversible lithium for insertion materials with different host structure

Characterization Techniques for Fuel Cells and Batteries (Zeis)

Student should be able to
• describe and explain diagnostics employed in the characterization and determination of Proton Exchange Membrane (PEM) fuel cells and battery performance.
• gain a more precise understanding of the physical and chemical processes that occur in PEM fuel cells and batteries based on knowledge of these diagnostic tools.
• start working on a master thesis in the field of electrochemical energy converters and storage devices.

Polymeric Materials (Ziener)

Students should be able to
• describe the fundamental properties of macromolecular materials and modern applications these materials.

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**Syllabus**

Innovation Management for Nanotechnology (Altmann)

• Nanotechnology as key technological developments in the 21st century, interdisciplinary field of research (engineering, natural, medical science)
• From science to technology to markets
• Tools of nanotechnology: Chromatographies, spectroscopies, microscopies, nanomanipulation
• Nanoscience: Nanochemistry, nanophysics, nanobiology, nanomedicine
• Innovation management for nanoscience (IMfN): Principles, project management for nanotechnology, new business development, business development
• Nanotechnology as enabler for industries: transportation, construction, optics, electronics, pharma and medicine
• Nanomarkets: Technology push from nanotech-solutions needed; market pull for nanotech-where it comes from; opportunities created by nanoscience; markets today
• Nanofinance: Financing R&D, financial tools for start-ups, portfolio management
• Nanofinance: Societal concerns, real and apparent dangers
• Ensuring sustainable business success

Hydrogen as Energy Carrier (Mohrdieck)

• Overview: Hydrogen as energy carrier, research fields, areas of application
• Hydrogen production: Methods, logistics and infrastructure
• Hydrogen storage: Non-compressed, compressed
• Hydrogen for Storage of Fluctuating Energies
• Hydrogen fueling technology
• Pathways of hydrogen production and use: Complete energy chain efficiency, emissions, comparison with other energy sources
• Fuel cell vehicles
• Visit of hydrogen and fuel cell laboratory, leakage test
• Visit of a hydrogen fueling station and fuel cell vehicle test drive
• Safety, regulations, codes and standards
• Tool for the visualization of energy chain efficiency results
• Future perspectives of hydrogen as an energy carrier
• Process, stationary and alternative applications
• Hydrogen - Fuel Cell - Efficiency – Entropy

Scientific, Economical and Ecological Aspects of the Energy Economy (Münch)

• German energy supply industry
• Energy sources exploited
• Technologies employed for energy provision
• Energy supply and consumption and the impact on the environment
• Future energy supply: Sustainable energy sources

Lithium Ion Batteries (Wohlfahrt-Mehrens)

• Secondary batteries (accumulators): Design principles, characteristics
• Lithium Ion Batteries: Basic principles, battery design, characteristics
• Lithium insertion materials: Basic mechanism, structural considerations, anodes and cathodes
• Electrolytes: Requirements, conductivity, stability window
• Solid Electrolyte Interface (SEI)
• Charge and discharge behavior of LIB, control strategies
• Degradation and corrosion mechanisms
• Current research topics
• Applications of LIB, related markets and energy policies
• Laboratory visit: Development of materials, test centre

Characterization Techniques for Fuel Cells and Batteries (Zeis)

1. In situ cell tests

• Steady state voltage-current measurements
• Polarisation and charge-discharge curves
• Impedance spectroscopy
• Neutron scattering
• Synchrotron radiation
2. Evaluation of cell components (Membranes, Separators, Electrolytes, Electrodes, Catalysts, Gas Diffusion Layers …)

- Structural analysis (SEM, TEM, XRD, microtomography, porosity determination)
- Elemental analysis (XRF, ICP-MS, EDX)
- Electrochemical surface area (BET, cyclic voltammetry)
- Catalytic activity (Rotating Ring Disk Electrode)
- Membrane degradation (Neutron scattering, Fenton test)

Polymeric Materials (Ziener)

- Block copolymers for nanoparticle synthesis
- Conductive polymers
- Liquid crystalline polymers
- Molecular imprinting
- Nanostructuring
- Porous polymeric materials
- Thermoreversible gels
- Shape memory polymers

**Literature**

Characterization Techniques for Fuel Cells and Batteries (Zeis):

- Handouts

Hydrogen as Energy Carrier (Mohrdieck)

- Züttel, Andreas; Borgschulte, Andreas; Schlapbach, Louis (eds.): Hydrogen as a Future Energy Carrier (Wiley-VCH, Weinheim, 1. Aufl.2008)

Innovation Management for Nanotechnology (Altmann):

- Handouts

Lithium Ion Batteries (Wohlfahrt-Mehrens):

  Chemical reviews (2004) 104 (10) Gesamter Band

Polymeric Materials (Ziener):

- Polymeric materials: J. M. G. Cowie, Polymers: chemistry and physics of modern materials, 2nd ed., 1994 and further references from scientific (materials) journals

Scientific, Economical and Ecological Aspects of the Energy Economy (Münch):

- Handouts

**Teaching and learning methods**

Lecture, seminar, excursions, depending on the course

3 credit point, 2 h/week
except *Polymeric Materials*  4 credit points, 3 h/week

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<th>Workload</th>
<th>Innovation Management for Nanotechnology (Altmann)</th>
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<tr>
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|          | Hydrogen as Energy Carrier (Mohrdieck)             |
|          | Summer term, total 90 h                            |
|          | • 28 h lecture (presence) incl. excursion (Daimler) |
|          | • 46 h preparation and revision of lecture          |
|          | • 16 h exam preparation                             |

|          | Scientific, Economical and Ecological Aspects of the Energy Economy (Münk) |
|          | Summer term, total 90 h                            |
|          | • 28 h lecture (presence)                           |
|          | • 46 h preparation and revision of lecture          |
|          | • 16 h exam preparation                             |

|          | Lithium Ion Batteries (Wohlfahrt-Mehrens)          |
|          | Winter term, total 90 h                            |
|          | • 32 h lecture (presence)                           |
|          | • 42 h preparation and post processing of lecture   |
|          | • 16 h exam preparation                             |

|          | Characterization Techniques for Fuel Cells and Batteries (Zeis): |
|          | Winter term, total 90 h                            |
|          | • 32 h lecture (presence)                           |
|          | • 42 h preparation and post processing of lecture   |
|          | • 16 h exam preparation                             |

|          | Polymeric Materials (Ziener)                        |
|          | Winter term, total 120 h                            |
|          | • 48 h lecture (presence)                           |
|          | • 56 h preparation and post processing of lecture   |
|          | • 16 h exam preparation                             |

| Assessment | According to elective course either written exam(s) or oral presentation(s) |
| Grading procedure | Weighted average of graded exams according to credit points |
| Basis for   | Master thesis                                      |
### Additive Key Qualifications

Modules referring to Additive Key Qualifications

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<td>Head of Examination Committee (Prof. Dr. Rolf Jürgen Behm)</td>
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<tr>
<td>Instructor(s)</td>
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<tr>
<td>Recommended prerequisites</td>
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| **Learning objectives** | Students will acquire and/or improve their knowledge of German language. For Non-German students the „German Language“ courses are mandatory enabling them to handle every-day-situations in German. German students have the choice between various courses offered by the University's Language Center and Humboldt Center. Additionally, the ASQ Module will enhance the intercultural competence of all students as well as improve their abilities  
- to work in a team,  
- to orally communicate and present a specific scientific or non-scientific topic  
- to search literature related to a specific scientific topic  
- to plan and write a scientific report  
- to participate in project management |
<p>| Syllabus              | see course descriptions |
| Literature            | see course descriptions |</p>
<table>
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<tr>
<th><strong>Teaching and learning methods</strong></th>
<th>see course descriptions</th>
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<tbody>
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<td><strong>Workload</strong></td>
<td>see course descriptions</td>
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| **Assessment**                   | German language I, written exam  
                                | German language II, written exam  
                                | German language III, written exam  
                                | or equivalent for German native speakers |
| **Grading procedure**            | Weighted average of graded exams according to credit points |
| **Basis for**                    | MSc Energy Science and Technology |
## German Language Higher Qualification

*Modules referring to Additive Key Qualifications*

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Basis for

No english version available yet.
German Language
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<td>1st, 2nd and 3rd semester MSc Energy Science and Technology, 1st, 2nd and 3rd semester MSc Advanced Materials, 1st, 2nd and 3rd semester MSc Finance</td>
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<tr>
<td>Recommended prerequisites</td>
<td>Intensive German course offered by the Language Center before start of the 1st semester. German courses 1, 2 and 3 are based one on the other</td>
</tr>
<tr>
<td>Learning objectives</td>
<td>Development of language skills: Listening, speaking, reading, writing. German for Advanced Material, Energy Science and Technology and Finance 1 Level A1, CEFR (Common European Framework of Reference for Languages) Students should be able to • understand and use familiar, everyday expressions and very simple sentences, which relate to the satisfying of concrete needs. • introduce him/herself and others as well as ask others about themselves – e.g. where they live, who they know and what they own – and can respond to questions of this nature. • communicate in a simple manner if the person they are speaking to speaks slowly and clearly and is willing to help. German for Advanced Material, Energy Science and Technology and Finance 2</td>
</tr>
</tbody>
</table>
Level A2, CEFR

Students should be able to

• understand sentences and commonly used expressions associated with topics directly related to his/her direct circumstances (e.g. personal information or information about his/her family, shopping, work, immediate surroundings).
• make him/herself understood in simple, routine situations dealing with a simple and direct exchange of information on familiar and common topics.
• describe his/her background and education, immediate surroundings and other things associated with immediate needs in a simple way.

German for Advanced Material, Energy Science and Technology and Finance 3

Level B1, CEFR

Students should be able to

• understand the main points when clear, standard language is used and the focus is on familiar topics associated with work, school, leisure time, etc.
• deal with most situations typically encountered when travelling in the language region.
• express him/herself simply and coherently regarding familiar topics and areas of personal interest.
• report on experiences and events, describe dreams, hopes and goals as well as make short statements to justify or explain his/her own views and plans.

Syllabus

For the three courses alike:

• vocabulary training
• grammar training
• development of communication skills

Literature

Module description will be available shortly.

Teaching and learning methods

Communication, grammar and vocabulary training in class.

Workload

German for Advanced Material, Energy Science and Technology and Finance 1: Total 90 h
• 64 h exercise (presence); at least 85% compulsory attendance
• 14 h revision, homework
• 12 h exam preparation

German for Advanced Material, Energy Science and Technology and Finance 2: Total 90 h
• 56 h exercise (presence) at least 85% compulsory attendance
• 22 h revision homework
• 12 h exam preparation

German for Advanced Material, Energy Science and Technology
and Finance 3: Total 60 h

- 32 h exercise (presence) at least 85% compulsory attendance
- 16 h revision homework
- 12 h exam preparation

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Module description will be available shortly.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grading procedure</td>
<td>Module description will be available shortly.</td>
</tr>
<tr>
<td>Basis for</td>
<td>Module description will be available shortly.</td>
</tr>
</tbody>
</table>
## Master Thesis

**Modules referring to Master Thesis**

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>ECTS credits</strong></td>
<td>30</td>
</tr>
<tr>
<td><strong>Attendance time</strong></td>
<td>30</td>
</tr>
<tr>
<td><strong>Language of instruction</strong></td>
<td>English</td>
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<tr>
<td><strong>Duration</strong></td>
<td>1 Semester Semester</td>
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<tr>
<td><strong>Cycle</strong></td>
<td>each Semester</td>
</tr>
<tr>
<td><strong>Coordinator</strong></td>
<td>Head of Examination Committee (Prof. Dr. Rolf Jürgen Behm)</td>
</tr>
</tbody>
</table>

**Instructor(s)**

Habilitated permanent members of Ulm University, in case of external master theses complemented by scientists qualified on a comparable level and individually assigned by the Examination Committee.

**Allocation of study programmes**

Energy Science and Technology 4. Semester

**Recommended prerequisites**

minimum of 75 ECTS points

**Learning objectives**

Students are able

- to survey the project related literature
- to design or optimize an experimental set-up
- to project specific preparational and analytical tools
- to acquire data acquisition & analysis including error considerations
- to apply their acquired knowledge on writing scientific reports in order to deliver a scientifically consistent and formally complete thesis
- to prepare and deliver a scientific presentation based on the accomplishments gained during the thesis work.

**Syllabus**

Research topic

**Literature**

depends on research topic
<table>
<thead>
<tr>
<th><strong>Teaching and learning methods</strong></th>
<th>independent work (experimental work, lab work etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Workload</strong></td>
<td>Total: 900 h</td>
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<tr>
<td><strong>Assessment</strong></td>
<td>Written research orientated thesis</td>
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<tr>
<td><strong>Grading procedure</strong></td>
<td>Reports by two examiners</td>
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<tr>
<td><strong>Basis for</strong></td>
<td>MSc Energy Science and Technology</td>
</tr>
</tbody>
</table>