Module Descriptions

Master of Science Advanced Materials

Absorption: Nanomaterials

Examination Regulations in the Version of: 2012
Index

Materials Science

Materials Science I -Lecture and Laboratory ................................................................. 1
Materials Science II -Lecture and Laboratory .............................................................. 4

Chemistry, Physics, Engineering

Chemistry for Advanced Materials ............................................................................. 7
Engineering ................................................................................................................ 11
Physics ....................................................................................................................... 13

Nanomaterials

Nanomaterials II .......................................................................................................... 16
Nanomaterials I ........................................................................................................... 20

Elective Courses

Electives for Advanced Materials .............................................................................. 23

Additive Key Qualifications

Additive Key Qualifications ......................................................................................... 24
Additive Key Qualifications ......................................................................................... 25
German Language ....................................................................................................... 27

Master Thesis

Master Thesis ............................................................................................................... 30
# Materials Science I - Lecture and Laboratory

**Modules referring to Materials Science**

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<tr>
<td>Coordinator</td>
<td>Prof. Dr. U. Herr, Faculty of Engineering and Computer Science</td>
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## 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.

**Laboratory Materials Science I**

Students should be able to

- operate modern instruments
- apply their fundamental knowledge of Materials Science
- present and report own experimental work/results

## Syllabus

**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.

Laboratory Materials Science I

• X-ray diffraction (2 sessions)
• Phase transformations
• Atomic force microscopy
• Microstructure (2 sessions)
• Mechanical properties

Literature

• Ashby M. F. and D. R. H. Jones: Engineering Materials 1. 2nd ed., Butterworth-
• Ashby, M.F. and D. R. H. Jones: Engineering Materials 2. 2nd ed., Butterworth-
• Callister, W.D.: Materials Science and Engineering: An Introduction. 6th ed.,

Teaching and learning methods

Materials Science I

5 credit points
Lecture 3 h/week
Solving problems 1 h/week

Laboratory Materials Science I

5 credit points
Laboratory: 3 h/week
Seminar: 1 h/week

Workload

Materials Science I: Total 150 h

Lecture:
48 h presence
38 h preparation and revision

Solving problems:
16 h presence
32 h revision

Exam:
16 h preparation

Laboratory Materials Science I: Total 150 h

42 h presence
65 h preparation, revision, writing reports
43 h preparation of presentation, presentation, paper writing
**Assessment**
No english version available yet.

**Grading procedure**
Grading: Result of the written examination and the seminar presentation grade, each one with 1/2 of the module weight.

**Basis for**
Modules *Materials Science II*, *Nanomaterials I and II*, *Biomaterials I and II*
Materials Science II -Lecture and Laboratory
Modules referring to Materials Science

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<td>Students should be able to</td>
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<td>• interpret the influence of the processing of a metallic alloy, ceramic and polymeric substance on its microstructure and properties.</td>
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<td>• relate the structure of a composite material to improved strength and toughness.</td>
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<td>• select appropriate materials and processing routes for the realization of an engineering design goal, based on properties and performance characteristics.</td>
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<td>• operate modern instruments</td>
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<td>• be able to present and report own experimental work/results</td>
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Syllabus
Materials Science II

• Application of basic concepts introduced in part 1 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

Laboratory Materials Science II

• Lambda probe
• Optical properties of ceramics
• Kerr magnetometry and microscopy
• Impedance spectroscopy
• Elastic properties
• Hydrogen storage

Literature


Teaching and learning methods

Materials Science II

5 credit points
Lecture 3 h/week
Exercise 1 h/week

Laboratory Materials Science II

5 credit points
Laboratory: 3 h/week
Seminar: 1 h/week

Workload

Materials Science II: Total 150 h

Lecture:
42 h presence
50 h preparation and revision

Solving problems:
14 h presence
28 h revision, solution of exercises

Exam: 16 h preparation

Laboratory Materials Science II: Total 150 h

36 h presence
71 h preparation, revision, writing reports
43 h preparation of presentation, presentation, paper writing
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Chemistry for Advanced Materials
Modules referring to Chemistry, Physics, Engineering

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<td>Prof. Dr. T. Bernhardt, Prof. Dr. M. Fichtner, Dr. E. Mena-Osteritz, Faculty of Natural Sciences</td>
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Learning objectives

**Introductory Chemistry**

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-pKa/pKb-value to analyze the properties of water, oxo-acids, weak 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

**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.

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

Introductory Chemistry

• 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, pKa- and pKb-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

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.

Materials Chemistry

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

Organic materials:
• Structure: Chemical structure of organic oligo- and polymers.
• Material formation: Intermolecular interactions, introduction to supramolecular chemistry
• Classes of organic materials: Dyes, polymers, conductive oligo- and polymers.
• Structure-property relationship of organic materials

**Literature**

**Introductory Chemistry:**

**Physical Chemistry:**

**Materials Chemistry:**

**Teaching and learning methods**

**Introductory Chemistry**
3 credit points
Lecture, 2 h/week

**Physical Chemistry**
4 credit points
Lecture 2 h/week
Problem solving 1h/week

**Materials Chemistry**
4 credit points
Lecture 3 h/week

**Workload**

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<tr>
<th>Course</th>
<th>Total Hours</th>
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<td>90 h</td>
<td>32 h</td>
<td>44 h</td>
<td>14 h</td>
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<tr>
<td>Physical Chemistry</td>
<td>120 h</td>
<td>32 h</td>
<td>34 h</td>
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<td>Problem solving</td>
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**Assessment**

The grade of the module will be the grade of the written exams. No prerequisites are necessary for exam registration for 10952 and 12372. Prerequisite for exam registration for 10875 is passing the pre-course (to be defined by the examiner).

**Grading procedure**

The grade of the module will be the average of the individual exam grades weighted by the credit points of the individual exams.

**Basis for**

Module *Nanomaterials I, II*, *Biomaterials I, II*
## Engineering
**Modules referring to Chemistry, Physics, Engineering**

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<td>Prof. Dr. F. Scholz, Faculty of Engineering and Computer Science</td>
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<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
**Physics**

Modules referring to Chemistry, Physics, Engineering

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<tr>
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<td>Dr. M. Amirkhani, apl. Prof. Dr. B. Koslowski, Dr. A. Plettl, Faculty of Natural Sciences</td>
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**Allocation of study programmes**

First and second semester MSc Advanced Materials

**Recommended prerequisites**

Fundamentals of physics (mechanics, electricity, optics, quantum mechanics) and Fundamentals of mathematics (differentiation, integration, complex calculus, ordinary and partial differential equations)

**Learning objectives**

Solid State Physics

Students should be able to

- relate the atomic structure of materials to physical properties.
- classify materials according to atomic structure and involved chemical bonds.
- describe electrons in a solid state system: atom vs. solid.
- describe lattice vibrations and its influence on material properties: classical vs. quantum mechanical description, statistics of bosons.
- explain optical properties of dielectrics and metals by microscopic models.
- understand that classical physics often fails to predict material properties and quantum effects have to be taken into account.

Physics Laboratory

Students be able to

- determine basic properties of a solid experimentally by
  - structure analysis by X-ray diffraction
  - electronic core level analysis by X-ray photoelectron spectroscopy
  - electric conductivity measurement.
- use cryostats to perform experiments at low temperature.
• design and carry out advanced experiments in solid state physics.
• write scientific lab reports.

### Syllabus

**Solid State Physics**

- Basic classification of solids by means of structure, bonds and properties.
- Experimental determination of structure.
- Lattice vibrations and phonons: specific heat.
- Properties of the electron shell in solids, free electrons.
- Optical properties of solids.

**Physics Laboratory:**

- Specific heat of simple metals between 2 K and 20 K
- Advanced measurement techniques: Application of a Lock-in amplifier
- Determination of electrical conductivity of metals and semiconductors between 2 K and 70 K
- X-ray photoelectron spectroscopy (XPS) on Au and Au$_2$O$_3$
- Optical properties of Au films and Au nanoparticles.

### Literature

**Solid State Physics**:


**Physics Laboratory:**

- Handouts

### Teaching and Learning Methods

**Solid State Physics**

- 5 credit points
- Lecture 3 h/week
- Tutorial/Problem solving 4 x 2h

**Physics Laboratory**

- 4 credit points
- 4 h/week

### Workload

**Solid State Physics:** Total 150

- Lecture: 48 h lecture
  - 68 h preparation and post-processing
- Tutorial: 8 h presence
  - 8 h solving problems, revision
- Exam: 2 h exam + 16 h preparation

**Physics Laboratory:** Total 120 h

- 20 h laboratory (presence)
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Nanomaterials II
Modules referring to Nanomaterials

Code 8822871411
ECTS credits 8
Attendance time 6
Language of instruction English
Duration Semester
Cycle keine Angaben
Coordinator Prof. Dr. J. R. Behm, Faculty of Natural Sciences
Instructor(s) PD Dr. J. Bansmann, Prof. Dr. R. J. Behm, Prof. Dr. T. M. Bernhardt, Prof. Dr. T. Weil, PD Dr. U. Ziener, Faculty of Natural Sciences
Prof. Dr. P. Unger, Faculty of Engineering and Computer Science

Allocation of study programmes Third semester MSc Advanced Materials, focus Nanomaterials

Recommended prerequisites Modules Materials Science I and II, Nanomaterials I

Learning objectives

Micro- and Nanotechnology
Students should be able to
• describe modern technologies used for fabricating materials with micro- and nanometer-scale structures
• address these technologies with respect to their advantages/disadvantages, limits, costs and applicability for industrial production

Functional Properties of Nanomaterials
Students should be able to
• describe the physical properties of nanomaterials resulting from constraints on their nanoscale organization
• analyze structure-function relationships at the nano-scale
• discuss how analyzing and understanding nanoscale features of materials can open up new routes for knowledge-based design of functional nanomaterials

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

Principles in Structure Formation in Nanomaterials

Students should be able to

• analyze surface physical and chemical properties of complex systems
• apply the fundamental knowledge of processes on surfaces to other systems
• discuss the kinetics of reactions on surfaces in model systems
• describe the basics of electrochemistry at surfaces
• discuss the physics and chemistry of small clusters (gas phase)

**Syllabus**

**Micro- and Nanotechnology**

Techniques for preparation and characterization of various nanostructured materials and their applicability for industrial production processes

• Basic technological processes for lithography and pattern transfer techniques
• Application of these technologies in fabrication processes for nanostructured materials
  - CMOS and III-V technology
  - Micromechanics
  - Magnetic thin-film heads
  - Flat-panel displays
  - Micro optics
  - X-ray optics
  - Quantum-effect electronic devices
• Discussion of important original publications
• Performance of hands-on experiments in the clean room

**Functional Properties of Nanomaterials**

• Nanoscience: What is it all about? Examples, approaches.
• Analytical tools in nanoscience
• Preparations of nanostructures and nanoparticles
• Properties of nanostructures:
  1) Electronic and electrical properties
  2) Optical properties
  3) Magnetic properties

**Polymeric Materials**

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

**Principles in Structure Formation in Nanomaterials**

1. Surface structuring and nanoparticles:

• Classes of chemical reactions/processes
• Growth modes in growth processes
• Elementary surface processes during film growth
2. Applications of nanoparticles:
   • Usage in heterogeneous catalysis
   • Basic types of bimolecular catalytic reactions

3. Cluster based materials:
   • Chemisorption (dissociative/molecular) and molecular physisorption
   • Cluster structure calculations based on the Lennard-Jones (LJ) interaction
   • Potential, cluster mass spectra
   • Carbon cluster structures
   • One-dimensional metal structures

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**Literature**


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**Teaching and learning methods**

**Micro- and Nanotechnology (Unger)**

4 credit points
Lecture, 2 h/week
Exercises, 1 h/week

**Functional Properties of Nanomaterials (Bansmann)**

3 credit points
Lecture, 2 h/week

**Principles of Structure Formation in Nanomaterials (Behm, Bernhardt)**

3 credit points
Lecture, 2 h/week

**Polymeric Materials (Ziener)**

3 credit points
Lecture, 2 h/week
Seminar, 1 h/week

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**Workload**

Micro- and Nanotechnology: Total 120 h
Lecture: 32 h presence  
48 h preparation and post-processing

Exercises: 16 h presence  
24 h preparation and post-processing

Functional Properties of Nanomaterials: Total 90 h  
32 h presence  
58 h preparation and post-processing

Principles of Structure Formation in Nanomaterials: Total 90 h  
32 h presence  
58 h preparation and post-processing

Polymeric Materials: Total 90 h  
Lecture: 32 h presence  
28 h preparation and post-processing

Seminar: 16 h presence  
14 h preparation of presentation

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## Nanomaterials I

Modules referring to Nanomaterials

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<td>Prof. Dr. K. Gottschalk, Faculty of Natural Sciences</td>
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| Instructor(s)         | Apl. Prof. Dr. B. Koslowski, Faculty of Natural Sciences  
                        | Prof. Dr. U. Herr, Prof. Dr. C. Krill, Dr. U. Simon, Faculty of Engineering |
| Allocation of study programmes | Second and third semester MSc Advanced Materials , focus Nanomaterials |
| Recommended prerequisites | Modules Physics , Materials Science I |
| Learning objectives   | Advanced Physics of Materials  
                        | Students should be able to  
                        | • relate macroscopic properties of materials (electronic, optical, magnetic) to  
                          | microscopic properties (e.g., structural symmetry).  
                        | • relate macroscopic optical materials properties to microscopic models.  
                        | • describe the most important phenomena (e.g., dia-, para-, ferro-, antiferro-,  
                          | ferrimagnetism) and the basic ideas to explain them microscopically.  
                        | Computational Methods in Materials Science  
                        | Students should be able to  
                        | • recognize the interplay between length/time scales and the computational  
                          | methods used for simulation in materials science  
                        | • describe the theoretical underpinnings of the finite element method, the phase  
                          | field method, molecular dynamics and the Monte Carlo method  
                        | • to explain the strengths and limitations of each of these simulation methods  
                          | based on practical experience acquired during computer lab exercises  
                        | • select an appropriate simulation method for solving a given materials science  
                          | problem computationally |
Syllabus

Advanced Physics of Materials

• From free electrons to nearly free electrons: band structure & band gaps, Fermi surfaces, semiconductors, insulators
• Quasi-classical description of electron dynamics: effective mass, electrons & holes
• Semiconductors: Effects of doping
• Optics of metals: plasmons
• Magnetism: Curie law, Hund’s rule, Pauli susceptibility, ferromagnetic phenomena & descriptions

Computational Methods in Materials Science:

• What is a model?
• Modeling in materials science
• Simulation vs. modeling
• Numerical solution of differential equations using methods of statistical mechanics, Monte Carlo methods, Molecular dynamics phase-field models
• Finite element (FE) method

Literature

For general literature on solid state physics see module Physics

Additionally:

• Koonin S. E. and D.C. Meredith: Computational Physic, Addison-Wesley, 1990.
• Handouts

Teaching and learning methods

Advanced Physics of Materials

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

Computational Methods in Materials Science

4 credit points
Lecture 2 h/week
Computer lab 2 h/week

Workload

Advanced Physics of Materials: Total: 120 h

Lecture: 28 h presence
32 h preparation and post processing
Problem solving: 14 h presence
30 h preparation and post processing
Exam: 16 h preparation

Computational Methods in Materials Science: Total: 120 h

Lecture: 28 h presence
32 h preparation and post processing
Computer lab: 28 h presence
16 h preparation, post processing, report writing
Exam: 16 h preparation

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|                     | Master’s Thesis |
### Electives for Advanced Materials

**Modules referring to Elective Courses**

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### German Language

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**Allocation of study programmes**

1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} semester MSc Advanced Materials
1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} semester MSc Energy Science and Technology
1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} semester MSc Finance

**Recommended prerequisites**

Intensive German course offered by the Language Center before start of the 1\textsuperscript{st} semester.
German courses 1, 2 and 3 are based on the other

**Learning objectives**

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

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

Menschen – Deutsch als Fremdsprache, Max Hueber Verlag, 2013.
Kursbuch A1, A2 and B1

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)
• 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)
• 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)
• 16 h revision homework
• 12 h exam preparation
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