Module Handbook
Battery Materials & Technology (M.Sc.)

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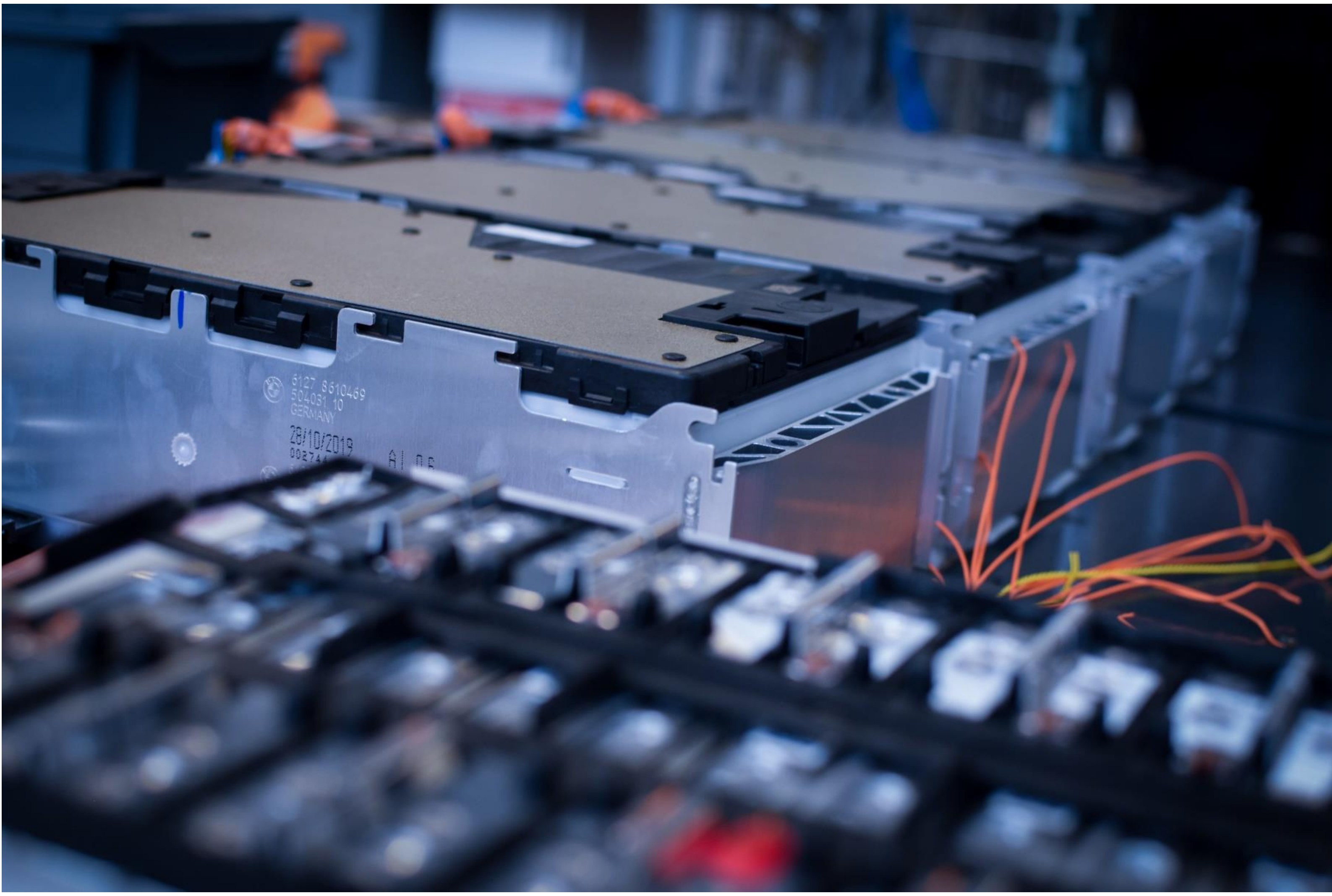
(start of studies from winter semester 2024/25)



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General explanations

Sustainable energy supply solutions will be one of the most important challenges facing humanity in the coming decades. Questions in the field of e-mobility in particular pose a major challenge for Germany, as one of the countries with an extensive automotive industry. Well-trained specialists will be required to achieve top performance in research and development. Research in battery technology is highly interdisciplinary, requiring in addition to the basics of chemistry and materials science also good knowledge of electrical engineering and applied thermodynamics. Thus, high quality outcomes can only be achieved through the broad qualification of the graduates.

The core of the course is therefore a multidisciplinary educational approach from the natural sciences and engineering technology. Accordingly, the current program shares a fixed core curriculum with the predominantly German-taught Master’s course in *Batterietechnik (Battery Technology)*.

However, the Master's course *in Battery Materials and Technology* focuses increasingly on teaching natural science skills in the field of battery technology. The qualification goal of the course builds on this and, in addition to the qualifications required for practical use in the field of engineering science, it is also intended to convey material competence and the necessary analytical methodology, above all with a decidedly natural science focus.

The aim of the core competence of the natural science-oriented English-language course is to be able to understand and process problems along the entire value chain of the battery system, applying a holistic, interdisciplinary approach. The scientific specifics of the Master's degree program take into account the requirements and qualifications needed and thus open up excellent career prospects for the graduates.

Modular structure and academic degree

The course is structured in modules. Using modules to organise the course of study, in combination with awarding credit points (LP) according to the European Credit Transfer System (ECTS), facilitates comparability and transferability of academic achievements within the European framework. The standard period of study for the course is four semesters with a total of 120 credit points (LP); one LP corresponds to an average student workload of 30 hours.

The programme of studies can be started in the winter semester or in the summer semester. Relevant competencies acquired at domestic or foreign universities can be recognised as completed study and examination credits upon an approved application. The university course is organised in modules, which usually comprise 5 credit points. 30 credit points are to be completed per semester.

The aim of this study course structure is to complement the teaching of missing foundational knowledge, to acquire sound skills on a broad number of battery-related subjects, and to establish a focus in specific research areas.

Pending the completion of all examinations in the required performance scope, the University of Bayreuth grants the academic degree of a Master of Science (abbreviated as: M. Sc.).

Types of courses

Knowledge transfer usually takes place using certain types of course teaching tools.
These include lectures (V), exercises (Ü), seminars (S) and practical trainings (P):

- **Lectures** (Abbreviation: V) deal with important topics of the respective field in a comprehensive presentation. They impart basic and specialised knowledge as well as information on methodology.
- **Exercises** (Abbreviation: Ü) are usually held in parallel with the lecture and serve to analyse the problem definition and to supplement and deepen knowledge on individual topics.
- **Seminars** (Abbreviation: S) work with research problems on selected individual issues. They serve to deepen the knowledge through independent study of scientific literature and impart training of oral and written presentation skills.
- **Practical trainings** (Abbreviation: P) convey apprentice experience with hand-on experiments in the laboratory. Scientific tests, suitable for the teaching of principles, are conducted by the students under guidance, evaluated, and often also presented in protocols.

Exam system

The examination consists of **the module exams** including the written master's thesis. The module exams cover the contents of the corresponding module. The exam type of the module is described in the respective module description. Any necessary further information on the examination type will be provided by the examiner at the beginning of each respective teaching units.

Possible exam types are written examinations, oral examinations, presentations and contributions (see §11 PSO). If a module includes several examinations (portfolio examination), the weighting of the individual parts is given in brackets in fractions.

Overview of the modules

Study outline

The students will deepen basic background knowledge from their respective bachelor's programs with a battery-specific focus and they will significantly expand their interdisciplinary knowledge in the battery sector.

Through the **alignment modules**, students achieve a common interdisciplinary basis in the different disciplines of natural sciences and engineering sciences.

The first joint interdisciplinary courses are the **Battery Systems Technology** and **Battery Materials** modules, in which the topic of battery is taught from the material and system side in order to enable a holistic understanding of the battery. **Electrochemistry** is the fundamental science for all internal processes within a battery cell. Only a sound education in this area enables a fundamental understanding of the basic processes. Therefore, there are two modules from each of these three core courses. Accordingly, the corresponding modules take up a broad area in the first year of study.

The **compulsory choice modules** from the fields of natural sciences and engineering sciences (at least one module from the field of natural sciences must be chosen) facilitate the consolidation of individual knowledge along the diverse technological challenges of the entire battery value chain. They will lead to both specialisation and a holistic understanding of the battery.

The **research modules** allow students to apply their newly acquired knowledge creatively and critically to a current research topic from the field of battery technology. One research module can be carried out externally, abroad or in the form of an internship with a company.

The **research plan** serves as preparation for the master’s thesis. Current scientific papers are presented and discussed in front of a specialist audience. A literature review is conducted and hypotheses on the research project are presented.

The degree program concludes with the **master's thesis**, which will be prepared based on the research plan. Practical and international periods are possible within the regular study period.

Module structure

Full-time studies

Semester	5 LP	5 LP	5 LP	5 LP	5 LP	5 LP
1	Alignment Module	Alignment Module	Alignment Module	Battery Systems Technology 1	Battery Materials 1 or 2*	Electro-chemistry 1
2	Compulsory Choice Module	Compulsory Choice Module	Alignment Module	Battery Systems Technology 2	Battery Materials 1 or 2*	Electro-chemistry 2
3	Compulsory Choice Module	Research plan	Research Module		Research Module	
4	Master's Thesis					

This module structure is intended for both a start of studies in the winter and summer semester.

Part-time studies

Semester	5 LP	5 LP	5 LP
1	Alignment Module	Alignment Module	Alignment Module
2	Battery Systems Technology 1	Battery Materials 1 or 2*	Electro-chemistry 1
3	Battery Systems Technology 2	Battery Materials 1 or 2*	Electro-chemistry 2
4	Compulsory Choice Module	Compulsory Choice Module	Alignment Module

Semester	5 LP	5 LP	5 LP
5	Compulsory Choice Module	Research Module 1	
6	Research plan	Research Module 2	
7	Master's Thesis		
8			

This module structure is intended for both a start of studies in the winter and summer semester.

* Battery Materials 1 is offered every winter semester, Battery Materials 2 is offered every summer semester. The modules don't build on each other in terms of content so that students can start with whichever module is offered during their first semester and take the other module in their second semester (for part-time studies: their second and third semester, respectively).

Module descriptions

Alignment modules

The alignment modules are used to create a common basis for the students taking into account their prior education. These are introductory modules on areas in which the students have not yet reached certification.

During the admission process, the alignment modules are individually assigned from the catalogue of alignment modules below (see next pages). Four alignment modules, totalling 20 LP (credits), are to be completed by all students. Alignment modules should be completed during the first year of study.

Module title	**Fundamentals of Mathematics for Electrochemical Energy Storage Systems**
Responsibility	Junior professorship for Methods for Battery Management
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	The aim of the course is to deepen the knowledge in the field of mathematics by providing advanced knowledge in engineering mathematics required for other engineering courses. It provides an overview of relevant mathematical problems in electrical energy storage systems and knowledge of advanced mathematical methods needed to solve these problems. In addition, the course provides knowledge of how to apply these methods, including the use of modern computational tools.
Contents	The course covers various topics in advanced engineering mathematics: • Sequences and series, such as power series. This includes methods that can be used to study their properties, such as limit behavior and their utilization for approximating functions, e.g. Taylor polynomial approximation. • Multi-variable functions and methods for studying their properties, such as gradients and extrema. Further, least-squares approximation and numerical minimization using gradient-based methods are covered. • Complex numbers and functions and their application to the analysis of harmonic oscillations, e.g. in electrical circuits. • Fundamentals and advanced methods for ordinary differential equations (ODEs) and partial differential equations (PDEs). This includes for example the analytical solution of initial value and boundary value problems, ODE systems and state space representations, eigenvalues and eigenfunctions. In addition, numerical methods for solving ODEs and PDEs are covered. These include forward and backward Euler and other multipoint methods, e.g. Runge-Kutter. For PDEs, spatial discretization methods, such as finite volume methods, and different types of boundary conditions are covered. • Frequency domain transformations, which include the Fourier and Laplace transform. The methods are applied to the study time-dependent linear systems. • Probabilistic systems, which includes an introduction to the most important probability distribution functions and their application, e.g., to the study of system failures. In addition, algorithms for generating permutations are introduced. The application of the knowledge is illustrated and trained with relevant examples in the field of electrical energy storage systems, e.g., reaction systems, electrical equivalent circuits, mass and heat transport, and control. The use of advanced computational tools, e.g. Python, to solve applied mathematical problems is demonstrated.
Requirements	Advanced study skills; knowledge equivalent to a university Bachelor's degree in engineering, natural sciences or a related field, basic knowledge of mathematics.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester

Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Homework: 50 hours Exercises: 30 hours; Preparation and follow-up 10 hours, Exam preparation: 30 hours

Module title	**Fundamentals of Physics for Electrochemical Energy Storage Systems**
Responsibility	Chair for Theoretical Physics VII
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	This course aims to give students an overview of basic concepts and tools of physics as they pertain to batteries and their materials. Skills and concepts acquired in the lectures will be deepened in the accompanying exercises.
Contents	• Classical mechanics: Newtonian laws, energy, conserved quantities, Hamilton formalism, crystallography, symmetries, phonons • Electrodynamics: Coulomb Potentials, Poisson equation, plate capacitor model, currents, magnetism, Maxwell equations in vacuum and matter • Quantum mechanics: operators, quantisation, Schrödinger equation, quantum uncertainty, chemical bonds, orbitals, electronic energy levels • Thermodynamics and statistical mechanics: temperature, thermodynamic potentials, Laws of Thermodynamics, heat capacity, thermal expansion, heat conductivity, diffusion
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	German/English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 45 hours

Module title	**Fundamentals of Inorganic Chemistry for Electrochemical Energy Storage Systems**
Responsibility	Chair of Inorganic Active Materials for Electrochemical Energy Storage
Type of course	Lecture (3 SWS) and Exercises (1 SWS)
Desired learning outcomes	The objective is to refresh the basics of general and inorganic chemistry for students who had few ECTS in chemistry in their education. The course will provide all basic knowledge needed to later attend the courses in Battery materials. The focus of the course is on solid-state chemistry, i.e. the students will learn especially what governs the stability and properties of solids.
Contents	The course starts from the very basics of atomic structure and atomic models, to well understand the periodic system and the trends within. Basic quantum mechanics will be discussed to go beyond the Bohr model to the Schrödinger equation. The structure principles for multi-electron atoms will then be clarified, as well as the Octet rule. The course will then cover bonding between atoms, starting from the ionic bonding. The Madelung constant and Born-Haber cycle will be studied. Covalent bonding and hybridization are covered next, including Lewis structures, electronegativity, polar bonds and VSEPR. The LCAO method will be shown for simple molecules. Secondary bonding will be briefly touched upon. Then solids will be discussed based on their electrical properties. Insulators, semiconductors and metals. The origin of the band structure in solids will hence be discussed, as well as the influence of the crystal field on the electronic levels. Important (close-packed) crystal structures are also discussed. The last lectures will refresh specific topics: i) solubility and acids/bases, and ii) chemical kinetics and diffusion (Fick´s laws).
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 45 hours; Preparation and follow-up: 30 hours Exercises: 15 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Fundamentals of Physical Chemistry for electrochemical Energy Storage Systems**
Responsibility	Chair of Electrochemistry
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	Acquiring competence in the field of physical chemistry. Specifically, by the end of this course students should be able to: • Discuss the laws of thermodynamics and how they can be used to describe chemical systems. • Apply thermodynamic principles to compute properties of chemical systems in an equilibrium state. • Discuss the kinetic model of gases, the process of diffusion and describe motion of ions in liquids. • Discuss the empirical kinetic laws and apply them to describe the simple chemical reactions.
Contents	The lecture is divided in two parts: thermodynamics and kinetics. In simple terms thermodynamics dictates if a reaction can occur at all, whereas kinetics describes how fast (or slow) the reaction proceeds. The lecture will cover the following topics: • Properties of ideal and non-ideal gasses • The first Law of Thermodynamics • Entropy, The Second Law • The Third Law, Gibbs Free Energy, and Chemical Reactions • Chemical Equilibria in Mixtures, Electrolytes • Chemical Kinetics: 1st and 2nd Order Reactions If time allows, we will cover transition state theory and its thermodynamic aspects, i.e., the combination of thermodynamics and kinetics.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 15 hours; Exam preparation: 75 hours

Module title	**Fundamentals of Macromolecular / Organic Chemistry for Electrochemical Energy Storage Systems**
Responsibility	Chair of Polymer Materials for Electrochemical Energy Storage
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	The objective of this lecture is to refresh knowledge and acquire competences in basic organic chemistry and macromolecular chemistry. The lecture gives an overview of functional organic groups and discusses synthesis, characterization, and properties of the most common polymers.
Contents	The lecture teaches: • Relevance and use of organic materials in batteries • Brief history of polymers • Basic definitions: organic groups, degree of polymerization, number- and mass-average molecular weight, MWD, polymer topology. • Synthetic methods: step growth polymerization, chain growth poly-merization, emulsion polymerization, • Examples for industrially relevant polymers, high performance polymers, specialty polymers. • Analytical methods: colligative methods, viscosity measurements, SEC, • Material properties, polymers in the melt, phase transitions, mechanical properties, testing and rheology, thermal analysis, DSC, DMA, TGA • Polymer processing: extrusion, injection moulding, fibre spinning. • Introduction to binders, additives, and polymer electrolytes
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercise: 15 hours; Preparation and follow-up: 30 hours Exam preparation: 60 hours

Module title	**Fundamentals of Electrical Engineering for Electrochemical Energy Storage Systems**
Responsibility	Chair of Electronics for Electrical Energy Storage
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	Understanding of the physical electromagnetic effects occurring in electric resistors, capacitors, inductors, and transformers. Analyzing (node-voltage analysis) all kinds of electric networks containing voltage and current sources (DC and AC), resistors, capacitors, inductors, and transformers.
Contents	• The electrostatic field (i.e., electric charges and electric charge densities; Coulomb's law; Coulomb force; the electric field strength; the electric flux density and the electric flux; Gauss's law; field lines and equipotential lines; the electric potential; potential difference and electric voltage; work, power and energy; the electric induction and the electric polarization; the capacitance and the capacitor); • The stationary electric flow field (i.e., the electric current and the electric current density; Ohm's law in differential and integral form; conductivity and resistivity; the electric resistance and the electric resistor); • DC networks (i.e., ideal and real voltage and current sources; networks; one-port and two-port component; branch, mesh and node; Kirchhoff's circuit laws: Kirchhoff current law (KCL) and Kirchhoff voltage law (KVL)); • The magnetostatic field (i.e., magnets; the Laplace force; the Lorentz force; the magnetic field strength; the magnetic flux density, the magnetic flux and the magnetic total flux; Ørsted's law and Ampère's circuital law; the current linkage); • The electromagnetic field (i.e., Faraday's law of induction; Lenz's law; the self-induction; the inductance and the inductor; the inductive coupling and the mutual inductance; turns and windings; the transformer and the transformation ratio; Maxwell's equations); • AC networks (i.e., characteristic parameters of periodic signals; complex calculus with phasors and amplitude phasors; impedance and admittance; resistance und conductance; reactance and susceptance; active power, reactive power, apparent power and complex apparent power; power factor and displacement angle); • Transient states (i.e., continuity conditions in capacitors and inductors; analysis of networks with one storage element).
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 45 hours

Module title	**Fundamentals of Materials Science for Electrochemical Energy Storage Systems**
Responsibility	Chair of Electrode Design for Electrochemical Energy Systems
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	By the end of the course, students will be able to: • Apply the core principles of materials science to analyze ceramics and polymers. • Analyze the mechanical responses and phase diagrams of materials. • Critically evaluate the use of various characterization techniques for the analysis of materials. • Integrate knowledge of structure, properties, and processing for a comprehensive view of materials science and engineering.
Contents	This course introduces the core principles of materials science and engineering, emphasizing materials structures such as atomic and crystal arrangements, and the connections between microstructure elements like grain size and defects, and properties such as strength and ductility. A special focus will be on the behavior of ceramic and polymer materials, including phase transformation and the optimization of their physic-chemical attributes. The course also offers foundational knowledge about the composition, properties, and fabrication of ceramics and polymers. Modules encompass ideal / real crystals, defects, doping, diffusion, mechanical properties, phase diagrams, microstructure, and characterization. The curriculum's blend of fundamental and practical insights serves as a comprehensive foundation for future studies in materials science. The course concludes with a review module that synthesizes the key concepts, providing a perspective on this complex and evolving discipline.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Fundamentals of Signals and Systems for Electrochemical Energy Storage Systems**
Responsibility	Chair of Systems Engineering for Electrical Energy Storage
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	By the end of the course, students will be able to: • perform classification of signals and systems • apply convolution for simple problems • understand Fourier-Series, Fourier and Laplace transforms and apply these to solve simple problems • explain the relationship between signals and systems • master different approaches to mathematically describe the output-input behaviour • explain the relationship between transfer function and complex impedance • perform time discretization of continuous systems • explain and apply the Nyquist-Shannon sampling theorem • apply the z-transform to simple problems
Contents	The understanding of signals and systems is used in many specialized methods when dealing with batteries (i.e., impedance spectroscopy). This alignment module is intended to provide a basis for understanding basic modelling and simulation methods as applied to battery technology. It includes Fourier series, Fourier transform, Laplace transform in the application for the analysis of signals but also for the solution of differential equations. Basic signals like unit step, Delta-Dirac and pulse train are introduced. Hereby it becomes possible to switch between periodic and aperiodic signals, as well as between continuous-time and discrete-time signals and systems. Finally, the z-transform is introduced for discrete-time systems.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Fundamentals of Scientific Programming for Electrochemical Energy Storage Systems**
Responsibility	Chair of Physical Chemistry V
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	This course aims to give students an overview of basic concepts and tools of scientific programming as they pertain to the design, optimization and analysis of electrochemical energy storage systems and the underlying materials. Skills and concepts acquired in the lectures will be deepened in the accompanying exercises.
Contents	• Basics of Programming: Data types, control flow, functions, object-oriented programming, compiled vs. interpreted languages. • Implementing Scientific Algorithms: Code structure, libraries, and performance optimization. • Basics of High-Performance Computing: Parallelization, data management, benchmarking of program performance. • Applied Programming in Python: Package management, visualization and data analysis, independent realization of programming projects related to the simulation and analysis of battery materials.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 45 hours

Mandatory modules

The mandatory modules are Battery materials 1 and 2, Electrochemistry 1 and 2, and Battery systems technology 1 and 2. Each of these modules has 5 LP, for a total of 30 LP.
Moreover, two research modules, the research plan and the master's thesis must be carried out. These must be related to the topic of 'battery'. The topic is set by a professorship involved in the course of study.

Battery Systems Technology 1

Responsibility	Chair of Electrical Energy Systems, Chair of Systems Engineering for Electrical Energy Storage Junior professorship for Methods for Battery Management
Type of course	Lecture (2 SWS), Exercises (2 SWS) and practical training (1 SWS)
Desired learning outcomes	The objective is to acquire interdisciplinary competence in the field of battery systems technology. The students will gain an overview of the structure and function, the properties and behaviour, the use and operation of battery cells. They will get to know engineering methods and system-related questions from different domains of battery technology.
Contents	In addition to the construction and function of a battery cell, the manufacturing of the cell will be presented as well. Parameters relevant to the operation of a battery, such as capacity or power, as well as status variables such as standby voltage or charge state are introduced. The students learn about methods of charging, testing and characterization of battery cells and gain initial insights into the modelling and ageing of batteries. Other key aspects are safety and sustainability with regard to battery technology. The students learn about safety-critical behaviour with regard to batteries and suitable measures for safe operation. The students will be presented with aspects of the battery life cycle from raw materials to recycling.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 30 hours; Preparation and follow-up: 15 hours Practical training: 15 hours Exam preparation: 30 hours

Battery Systems Technology 2

Responsibility	Chair of Systems Engineering for Electrical Energy Storage, Chair of Electronics for Electrical Energy Storage
Type of course	Lecture (2 SWS), Exercises (2 SWS) and Seminar (1 SWS)
Desired learning outcomes	The objective is to acquire interdisciplinary competence in the field of battery systems technology. The students will gain an overview of the structure and function, the properties and behaviour, the use and operation of battery systems. They will get to know engineering methods and system-related questions from different domains of battery technology.
Contents	In addition to the general structure and function of a battery system, different topologies and architectures will be presented. Students will learn about the requirements of battery systems in applications such as in the energy grid or drive technology, as well as the degrees of freedom and fringe conditions of the design. Limits, parameters and state variables of battery systems are introduced, which play an important role in monitoring and battery management. Students get to know the components of a battery system such as sensors, electronics, power electronics, and charge regulators. They will get first insights into the methodology of state estimation, as well as the prognosis of performance, energy and service life, the mechanical design, and thermal management. Other aspects relevant for operation, such as ageing, failure, safety and functional safety of the battery systems, are introduced.
Requirements	Recommended: Individual alignment modules
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written examination (3/5) and presentation (2/5)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercises: 30 hours; Preparation and follow-up: 15 hours Seminar: 15 hours; Preparation and follow-up: 15 hours Exam preparation: 30 hours

Battery Materials 1

Responsibility	Chair of Inorganic Active Materials for Electrochemical Energy Storage, Chair of Inorganic Colloids for Electrochemical Energy storage
Type of course	Lecture (3 SWS) and Exercises (1 SWS)
Desired learning outcomes	Interdisciplinary acquisition of competence in the field of battery materials. The students will learn about the synthesis, structure and electrochemical properties of the most important electrode materials on the market, as well as those in the research stage. The course will focus on active materials.
Contents	Introduction to energy storage technologies, battery definitions and concepts, fundamentals of solid-state chemistry and material chemical concepts in the field of electrode processes and reactions. Phase diagrams and general electrode reactions. Thermodynamic factors influencing the voltage curve, from biphasic mechanisms to solid solution reactions. Detailed description of cathode and anode materials (focus on electronic and crystal structure, synthesis, reactivity and stability). Diffraction as a tool for detailed crystal structure determination, including operando studies. Introduction to common separators and electrolytes.
Requirements	None
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	1st / 2nd course semester Students starting their studies in winter semester should take Battery Materials 1 during their 1st semester, then Battery Materials 2 in the 2nd semester.
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 45 hours; Preparation and follow-up: 15 hours Exercises: 15 hours; Preparation and follow-up: 15 hours Exam preparation: 60 hours

Battery Materials 2

Responsibility	Chair of Polymer Materials for Electrochemical Storage, Chair of Inorganic Active Materials for Electrochemical Energy Storage, Chair of Inorganic Chemistry III
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	The objective of this lecture is to acquire interdisciplinary competence in the field of battery materials. The students will learn about the synthesis, structure, and electrochemical properties of the most important inactive (organic, polymeric) materials on the market, as well as those in the research stage. The focus is on passive components inside battery cells and analytical methods.
Contents	Lecture table of contents: • Introduction to energy storage technologies, battery definitions and concepts. • Fundamentals of polymer and organic chemistry, polymer synthesis, basic definitions, and polymer characterization. • Thermal and mechanical properties of polymers. • Binders and additives: examples, electrochemical and conductive properties, processing of electrode composites. • Electrolytes: liquid electrolytes, physical properties, electrochemical stability, SEI formation and effect on battery performance, flame-retardant additives. • Separators: fabrication methods, physical properties, role in battery safety and thermal runaway, next generation separators. • Basics of NMR spectroscopy and application to battery technologies • Typical NMR interactions: chemical shift, quadrupole, dipole, hyperfine, knight shift • Measurement principles for determining structural and dynamic properties, ion conduction. • Operando X-ray analytics (for example XRD, XAS, NMR)
Requirements	None.
Availability frequency / Duration	Every summer semester / 1 semester
Recommended semester	1st/2nd course semester Students starting their studies in summer semester should take Battery Materials 2 during their 1st semester, then Battery Materials 1 in the 2nd semester.
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 15 hours; Preparation and follow-up: 45 hours Exam preparation: 30 hours

Electrochemistry 1

Responsibility	Chair of Electrochemistry
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	Acquiring competence in the field of electrochemistry. Specifically, by the end of this course students should be able to: • Demonstrate how the electrochemical potential and chemical equilibria define the thermodynamic potential for an electrochemical reaction; • Discuss the validity and shortcomings of the Butler-Volmer equation to describe electrode kinetics; and be familiarized with alternate theories for describing electrode kinetics (Marcus' theory, Gerischer's theory and combinations / derivations thereof); • Understand and discuss the role of charge and mass transport in electrochemical systems; • Attain a general understanding of what happens (in terms of e.g. measured currents, concentration gradients, diffusion limitations, among others) when an electrochemical cell is pushed out of equilibrium via a step in the potential.
Contents	The lecture will cover the following themes: • Intro & Overview of Electrode Processes • Potentials and Thermodynamics of Cells • Kinetics of Electrode Reactions • Mass Transfer by Migration and Diffusion • Double-Layer Structure and Adsorption • Basic Potential Step Methods The exercises related to the lecture content may be partially incorporated into the planned in-person active time of the module
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 15 hours; Exam preparation: 75 hours

Electrochemistry 2

Responsibility	Chair of Electrochemistry, Chair of Electrode Design for Electrochemical Energy Storage
Type of course	Lecture (2 SWS), Exercise (1 SWS) and Practical training (1 SWS)
Desired learning outcomes	Acquiring competence in the field of electrochemistry, especially in terms of methodology (both theoretical and practical). Specifically, by the end of this course students should be able to: • Describe how linear and/or cyclic voltammetry can be used to characterize the thermodynamic and kinetic properties of an electrochemical reaction. • Describe how the method of impedance spectroscopy works and how it can be utilized to characterize solid samples as well as solid electrode-liquid interfaces. • Discuss the similarities and differences between controlled potential and controlled current methods for characterizing electrochemical systems. • Discuss the advantages and short-comings of convection-controlled electrochemical methods (hydrodynamic electrochemistry) • Proficiently build three-electrode and two-electrode cells, and confidently used the methods outlined above to characterize the cell performance. • Analyse electrochemical data using statistical techniques, including sensitivity analysis and asymptotic statistics. • Describe methods of optimal experimental design employing simulations for practical understanding.
Contents	The lecture extends from the Electrochemistry 1 Module and is partially based on content of "Electrochemical Methods: Fundamentals and Applications" (3rd Edition) textbook by Bard, Faulkner and White. The following methods will be covered: • Basic Potential Sweep Methods • Controlled-current Techniques • Methods Involving Forced Convection-Hydrodynamic Methods • Techniques Based on the Concept of Impedance The Impedance section will be complimented with the content of other textbooks, which will be shared at the beginning of the module. The latter portion of this course provides examines the statistical analysis of electrochemical experiments. Emphasis is placed on parameter inversion techniques, and regression analysis applied to electrochemical impedance spectroscopy as an example. The course also explores the application of both frequentist and Bayesian methodologies for experimental design, as well as concepts of active learning, rapid data acquisition, segmented models, and asymptotic analysis. Simulation-based learning is integrated throughout to reinforce the theoretical concepts with practical application. The practical training-part of this module will be hosted in the labs of the Chair of Electrochemistry. The precise experiments will depend on the available equipment at the start of the Module. Possible experiments are as follows: • Ionic conductivity determination of solid electrolytes (via impedance spectroscopy, two-electrode measurement) • Cyclic voltammetry of (quasi)reversible redox couples • Assembly and galvanostatic (constant-current) cycling of Li-ion coin cells

	• Double-layer capacitance characterization of inert electrolytes via cyclic voltammetry and impedance spectroscopy (three-electrode measurement) • Determination of electrochemical stability window of an electrolyte via stepwise voltammetry (two- or three-electrode measurement) • Rotating ring-disk electrochemistry: three-electrode measurement, calibration and determination of faradaic efficiency of generated oxygen.
Requirements	• For the Lecture and Exercise: None. • For the Practical training: Pass the Electrochemistry 1 Module Final Examination • Recommended: Math Alignment Module, Physical Chemistry Alignment Module
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Written examination (90-120 minutes) OR oral examination (20-40 min) (9/10) and contribution (practical training reports, 1/10).
Student work input in hours	Lecture: 30 hours; Exercises: 15 hours; Practical training: 15 hours; Preparation and follow-up: 45 hours Exam preparation: 45 hours

Research Module 1 and 2

The Research Modules 1 and 2 can be carried out at all chairs participating in the study program. Current topics offered by the respective chairs are published via eLearning. Additionally, if students are interested in a particular research topic or research question, they can approach the relevant chair and request this as a research module. Two different modules are not to be carried out at the same chair.
One research module can alternatively be carried out externally, abroad or in the form of an internship with a company.

Responsibility	Chairs or professorships involved in the course of study
Type of course	Project work and seminar (1 SWS)
Desired learning outcomes	Students should gain insight into the current research practice. In addition, they are to acquire experimental skills through independent laboratory work under guidance, and they are to practice team skills and train in presentation techniques.
Contents	The learning content relates to the current research projects of the Chair. The module includes experimental work, literary work, participation in work group seminars including their own presentation and the preparation of a protocol.
Requirements	Successful completion of individual alignment modules and three mandatory modules is compulsory. (total: minimum 30 LP)
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	3rd course semester
Language of instruction	English
ECTS credit points	10 LP
Module testing	Contribution (written report, 3/4) and presentation (1/4)
Student work effort in hours per module	Practical work and evaluation: 200 hours; Preparation: 25 hours; writing: 50 hours; presentation: 25 hours

Research Plan

Responsibility	Chairs or professorships involved in the course of study
Type of course	Project work and seminar (2 x 1 SWS)
Desired learning outcomes	In the course of this module, students will learn how to prepare a scientific research work. By taking into account the current state of the art, the students will formulate scientific hypothesis based on the available scientific literature, and propose the experimental plan required to verify them, including an appropriate time plan. At the end of this module, students will be able to present and discuss recent scientific works in front of a specialist audience and write a concise research proposal which is intended as a preparation of their future Master thesis.
Contents	For the research plan, students will choose a topic from the field of battery materials and technology in agreement with a chair, which can be used as preparatory work for the Master thesis. An up-to-date literature outline should be drawn up, placing current scientific works in the overall context. The essential questions concerning the planned research are presented in relation to each other. Hypotheses are to be clearly outlined, and a testing plan is to be established. Furthermore, the necessary instrumental prerequisites are to be clarified and the time and material requirements of the planned experiments subjected to a critical examination. The outcome of the research plan is to be summarized in a written report and a presentation. The presentation and subsequent discussion will serve to improve presentation skills and facilitate comprehensive feedback from BayBatt chairs and peers. Finally, students must attend the weekly BayBatt seminar, where current scientific works from the field of battery materials and technology are presented by BayBatt members and external guests from industry and academia.
Requirements	Recommended: Battery system technology 1+2, Battery materials 1+2, Electrochemistry 1+2
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Contribution (written report, 1/2) and presentation (1/2)
Course components	• Attendance of the BayBatt seminar during the whole semester • Independent development and presentation of a current scientific topic from the field of battery materials/battery technology, including a literature survey related to the assigned topic • Presentation of the topic to the supervising chair's working group, followed by an academic discussion. • Written report on the assigned topic
Student work input in hours	Active time: 30 hours Literature review, development of seminar presentation and report: 120 hours

Master's Thesis

Responsibility	Chairs or professorships involved in the course of study
Desired learning outcomes	Ability to independently work on a research-relevant battery- related problem; practice written and oral presentation and communication techniques.
Contents	Written paper on a current battery-related topic (master's thesis)
Requirements	Advanced study ability; Passing exams for at least 40 credits; Completed research plan module (see examination and study regulations §12 para 2 s. 3).
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	4th course semester
Language	English or German
ECTS credit points	30 LP
Module testing	Dissertation
Student work input in hours	Research, evaluation and written elaboration on the master's thesis Total: 900 hours

Compulsory choice modules

Three compulsory choice modules (5 LP each) must be completed, whereby at least one module must be chosen from the compulsory choice area "Natural Sciences".
The compulsory choice modules are to be selected from the following catalogue.

Natural sciences

Module title	**Advanced Polymer Materials for Batteries**
Responsibility	Chair of Polymer materials for electrochemical energy storage
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	The objective is to learn about the development and use of advanced polymer materials for next generation batteries. The lecture gives an overview of challenges and opportunities for polymers as binders, polymer nanostructures and templates, solid polymer electrolytes, and as active material (organic electrodes).
Contents	The lecture teaches: • Brief history of polymers and batteries, working principle of batteries and relevant KPIs. • Nomenclature and definitions: P_n, M_w, M_n, MWD, polymer topology, single chain models, chain conformation, ideal chain, Kuhn-segments, real chains. • Polymerization methods: step growth polymerization, chain growth polymerization, controlled methods (AROP, RAFT, ATRP). • Polymer examples: industrially relevant polymers, high performance polymers, and specialty polymers. • Polymer architectures: copolymers, stars, brush polymers, block copolymers. • Polymer nanostructures: Flory Huggins theory, self-assembly, microphase separation, templating. • Analytical methods: SEC, DLS/SLS, SAXS, TEM, SEM/EDX. • Electrode coatings, solid electrolyte interface and additives. • Solid polymer electrolytes: examples, properties, in-situ polymerization • Organic electrodes: examples for redox-active organic molecules and polymers, their synthesis, processing, and properties, as well as applications of organic batteries. • polymer recycling: metrics about plastic production and waste, recycling concepts and future perspectives biological and bio-based alternatives.
Requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	English
ECTS credit points	5 LP (credit points)
Module testing	Written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 15 hours; Preparation and follow-up: 45 hours Exam preparation: 30 hours

Module title	**Advanced Powder Diffraction Methods for Structural Analysis of Materials – From Theory to Practice**
Responsibility	Chair of Inorganic Active Materials for Electrochemical Energy Storage
Type of course	Lecture (2 SWS) and Practical training (2 SWS)
Desired learning outcomes	The lecture gives an introduction into x-rays, crystallography and diffraction methods. Particular attention is given to structural analysis with diffraction methods and related software packages. Students will learn all relevant topics for structure analysis with a broad theoretical background. The understanding of structure analysis methods is supported by the accompanying practical training, which will teach the usage of software packages like FullProf, Vesta, Fox, Bilbao Crystallographic Server.
Contents	The course will cover specifically the application of structure analysis to various inorganic materials, including typical battery materials from Li-ion, Na-ion, and K-ion batteries as well as solid-state-batteries. The lecture ranges from x-ray radiation properties to the experimental setup of a powder diffraction experiment and introduces the diffraction theory with a focus on powder methods. Relevant aspects of symmetry operations, subgroup-relations, crystallographic notations will be covered as well. The practical part will introduce the students to widely used open-source software packages and their usage. Students will train on diffraction measurements to perform all relevant steps of structure analysis: • Phase identification • Indexing and structure solution from powder data • Rietveld refinement of known structures • Group-subgroup relations as a tool for structural analysis • Critical assessment of the refinement results • pitfalls and frequently encountered errors in refinement strategies • Advanced topics: use of neutrons, Fourier maps, Bond-Valence sum methods, etc.
Requirements	Mandatory: individual alignment modules.
Availability frequency / Duration	Every summer semester / 1 semester
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Written or oral examination (2/3) and contribution (practical training report, 1/3)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Practical training: 30 hours Preparation and follow-up: 15 hours Exam preparation: 45 hours

Module title	**Colloids and Surfaces**
Responsibility	Chairs of Physical Chemistry
Type of course	Lecture (2 SWS) and Practical training (3 SWS)
Desired learning outcomes	The course will provide knowledge about advanced physical chemistry of colloids and interfaces. The surface force dominating colloidal systems will be presented as well wetting phenomena and low-Reynold number hydrodynamics. The analytical technique to characterize colloidal and interfacial properties will be introduced and practically applied by the students.
Contents	The lecture will cover: The solid/liquid, liquid/liquid and liquid/gas interface as starting point. The diffuse layer at interfaces will be treated in detail, including differential double layer capacitance and Grahame equation. Surface forces, with a special emphasis on van der Waals forces, diffuse layer overlap, depletion forces and steric forces are fundamental for understanding and tuning colloidal interactions and are therefore central to lecture. These topics will be followed by adsorption phenomena at interfaces, including the adsorption of lipids and polymers. Ternary systems and Pickering emulsions represent an important addition for liquid/liquid interfaces and the formulation of colloidal interactions. Wetting phenomena with an emphasis solid/liquid interfaces and real-world systems represent a further topic of the lecture with important practical applications. The DLVO theory and its consequences for colloidal stability will be treated in detail. The final topic will be low-Reynold number hydrodynamics and microfluidics. Throughout the lecture, the analytical methods of colloid and interface science will be introduced, such as electrokinetic methods, scattering techniques, scanning probe techniques or electrochemical and titration techniques. In the laboratory course the students will be introduced to the characterization of the interfacial and colloidal systems and familiarize with the concepts introduced in the lecture. The laboratory course will be based on methods, such as impedance spectroscopy, quartz micro balance, microfluidics, optical and scanning probe microscopy.
Requirements	none
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German / English
ECTS credit points	5 LP
Module testing	Written or oral examination (3/5) and contribution (practical training report, 2/5)
Student work input In hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Practical training: 45 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Computational Materials Design**
Responsibility	Chair for Theoretical Physics VII
Type of course	Lecture (2 SWS) and Exercises (1 SWS)
Desired learning outcomes	Aim of this course is to provide basic competencies on the field of computational materials' design. Students will gain an overview of battery-relevant materials properties and the computational methods for their computation. Finally, students will get a basic introduction into machine learning methods for the prediction of such properties.
Contents	• <u>Structural materials' properties:</u> crystal structures, crystal stabilities, elastic constants, crystal vibrations and phonons, thermal properties, thermal expansion, heat conductivity • <u>Electronic materials' properties:</u> density of states, Fermi-Dirac statistics, heat capacity, Bloch theorem, Conductivity • <u>Computational Methods:</u> theoretical background of density functional theory, Hohenberg-Kohn theorems, Kohn-Sham density functional theory, exchange-correlation functionals, local density and generalised gradient approximations, advanced density functional theory • <u>Machine learning:</u> concepts, neural networks and kernel-based approaches advantages and disadvantages of machine learning
Requirements	Recommended: alignment module physics or basic physics & quantum mechanics
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercises: 15 hours; Preparation and follow-up: 30 hours Exam preparation: 60 hours

Module title	**Electrochemical Energy Systems and Energy Conversion**
Responsibility	Chairs of Physical Chemistry
Type of course	Lecture (2 SWS) and Practical Training (3 SWS)
Desired learning outcomes	Students are familiarized with the possibilities and applications of modern electrochemical energy systems and energy conversion.
Contents	The lecture deals with properties, processes and interfaced for electrochemical storage and conversion of energy. The focus is on general cell concepts, modern semiconducting electrodes and electrochemical analysis fundamentals. The following aspects are covered: • General electrode processes (electron transfer, materials transport) • Overview of electrochemical cells • Electrochemical analysis such as cyclic voltammetry and impedance spectroscopy • Electrocatalysis and photoelectrochemistry (water splitting, …) • Methods for operando analytics. • Understanding catalytic surface and interface processes from first principles: Density functional modelling of surface adsorption, adsorption isotherms, (electro)chemical potentials, transition state theory. • Modern theory of (electro)catalysis at surfaces: Microkinetic models, mean-field and steady state approximations, the Sabatier principle and its limitations. In the laboratory course (practical training), the students are familiarised with the presented measurement methods, cell concepts and the materials used in them on the basis of selected examples. Under the supervision of experienced staff of the respective chairs, this includes in particular electrochemical characterisation methods for investigating the properties and modes of operation of electrochemical cells, electrodes and systems.
Requirements	none
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German / English
ECTS credit points	5 LP
Module testing	Written or oral examination (3/5) and contribution (practical training report, 2/5)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Practical training: 45 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Impedance Methods for Interface Characterization in Energy Storage Systems**
Responsibility	Chair of Electrochemistry
Type of course	Lecture (2 SWS) and Seminar (1 SWS)
Desired learning outcomes	This module aims to deepen the expertise of the students in the method of electrochemical impedance spectroscopy for interfacial characterization. The fundamentals of the method will be presented, and the students will have the opportunity to become proficient in the analysis of impedance spectra of interfaces relevant to energy storage systems.
Contents	The lecture will cover various process models to describe impedance spectra, including but not limited to, equivalent circuit analogs and kinetic models. Moreover, frequency dispersion and its relevance to electrode roughness as well as porous electrodes will be discussed. Finally, the challenges for interpreting 2- vs. 3- electrode impedance responses will be presented. At the end of the lecture, topics will be assigned to each student from which they need to prepare a presentation, including their own assessment/interpretation of the impedance results.
Requirements	Recommended: • Electrochemistry 1 and Electrochemistry 2 • Individual alignment modules
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Written (90-120 minutes) or oral (20-40 min) examination (3/4) and presentation (1/4).
Student work input in hours	Lecture: 30 hours, Preparation and follow-up: 30 hours Seminar: 15 hours, Preparation and follow-up: 30 hours Exam preparation: 45 hours

Module title	**Nanochemistry**
Responsibility	Chair of Inorganic Colloids for Electrochemical Energy storage Chair of Inorganic Chemistry III
Type of course	Lecture (2 SWS) and Practical training (3 SWS)
Desired learning outcomes	In this course, students acquire a sound overview of current developments in the field of solid inorganic materials with a focus on aspects of nanochemistry.
Contents	The lecture presents properties, applications and fundamental aspects of solid inorganic functional materials. Emphasis is placed on the mechanisms of different synthesis routes as well as on modern analytical strategies. The following points will be covered: • Inorganic nanotechnology as well as colloids, pigments, nanorods and nanowires. • Inorganic composites and fillers including biogenic materials such as nacre and bone tissue. • Polymorphism and "crystal engineering" of molecular systems and their influence on active ingredient production • Supramolecular inorganic chemistry and host-guest compounds. • Semicrystalline and amorphous materials such as glasses, glass ceramics, phase transfer materials and photonic crystals In the practical training, students deepen their practical skills by working on a current research project in the relevant working groups under the guidance of an experienced doctoral student.
Requirements	None
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German / English
ECTS credit points	5 LP
Module testing	Written or oral examination (3/5) and contribution (practical training report, 2/5)
Student work input In hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Practical training: 45 hours; Preparation and follow-up: 15 hours Exam preparation: 30 hours

Module title	**Post Li-ion Battery Technologies**
Responsibility	Chair of Inorganic Active Materials for Electrochemical Energy Storage
Type of course	Lecture (2 SWS) and Seminar (1 SWS)
Desired learning outcomes	The objective is to present to the students the array of technologies which are at the research stage and being developed as "post Li-ion", i.e. as improvements beyond the current Li-ion batteries, representing the state of the art. Examples include Na-ion, solid-state-batteries, Zn-based and Li-S batteries, as well as nanostructuring solutions to improve materials properties.
Contents	The course will cover specifically: Na-ion and K-ion batteries; solid-state-batteries (including a detailed discussion on ionic conductivity); multivalent chemistries (Mg, Ca, Al); Zn-based batteries as well (including aqueous), Li-S and Li-air batteries. The course will also cover nanostructuring solutions for advanced electrodes in Li-ion and post-Li-ion batteries.
Requirements	Recommended: individual alignment modules and Battery Materials 1 or 2
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination (3/4) and presentation (1/4)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Seminar: 15 hours; Preparation and follow-up: 30 hours Exam preparation: 45 hours

Engineering sciences

Module title	Battery Data Analytics
Responsibility	Chair of Systems Engineering for Electrical Energy Storage
Type of course	Lecture (2 SWS), Exercises (2 SWS) and Seminar (1 SWS)
Desired learning outcomes	By the end of this course students will be able to: • Apply Python to import, clean, filter and visualize data typical for battery domain • Use Jupyter Notebooks to structure, perform and present data analysis • Apply basic statistical methods to battery data • Reduce dimensionality of data • Apply machine learning to extract parameters for known modules and discuss the results • Apply unsupervised machine learning to battery data and interpret results • Evaluate when to use which method • Present the result of a data analysis
Contents	Following an introduction to the use of Python and Jupyter Notebooks for structuring, performing, and presenting data analyses with a focus on data from the battery domain, basic statistical methods and preprocessing techniques will be introduced. Using linear regression and advanced methods, parameters for known or assumed models will be derived. Unsupervised machine learning methods, such as clustering and dimensionality reduction, will also be introduced. Support Vector Machines will be used for categorization and prediction. Finally, an outlook on the application of neural networks will be provided, explaining the basic principles with a simple example, extending to physically informed neural networks, and discussing the potentials of transfer learning. In addition to working on exercises, students will carry out a data analysis project, in which they will independently conduct an analysis and present their results.
Requirements	Basic knowledge in programming; BST1 and BST2 recommended
Availability frequency / Duration	Starting in summer semester 2025, Then annually in winter semester / 1 semester
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Contribution (paper, 3/5) and presentation (2/5)
Student work input in hours	Lecture: 30 hours, preparation and follow-up: 15 hours Exercises: 30 hours, preparation and follow-up, Paper: 45 hours Seminar: 15 hours, preparation: 15 hours

Module title	**Battery-Management-Systems**
Responsibility	Junior professorship for Methods for Battery Management
Type of course	Lecture (2 SWS) and Practical training (2 SWS)
Desired learning outcomes	You will be familiar with the main tasks, functions and components of a battery management system. You know which components, models and algorithms are typically used to implement the functions and know the advantages and disadvantages of different approaches. You will understand how the methods work and be able to apply them in practice. You will be able to evaluate different approaches and select suitable methods.
Contents	Overview of the necessity and functions of a battery management system (BMS). Overview of hardware components and possible topologies and technologies. Basics of the essential functions. These include, for example, active and passive balancing, safety functions, model-based and non-model-based methods for estimation of the state of charge and state of health. Overview of ageing models and their application in battery management. Fundamentals of model-based peak power prediction and model-based control. The practical application of the methods learned in the laboratory is also covered.
Requirements	Advanced study skills; engineering knowledge to the extent of a university bachelor's degree program, especially in mathematics and electrical engineering; basic knowledge in the field of battery technology.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	In winter semester: English In summer semester: German
ECTS credit points	5 LP
Module testing	Written examination (3/5) and contribution (practical training report, 2/5)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up 30 hours Practical training: 40 hours; Preparation and follow-up: 20 hours Exam preparation: 30 hours

Module title	**Computational Electrode Design of Electrochemical Energy Storage**
Responsibility	Chair of Electrode Design for Electrochemical Energy Systems
Type of course	Lecture (2 SWS), Exercise (1 SWS), and Practical Training (1 SWS)
Desired learning outcomes	By the end of this course, students will: • Master the use of computational tools needed to analyse and design electrochemical systems. • Be able to write programs aiming at understanding and designing electrodes. • Conduct simulations using finite element analysis and related techniques. • Formulate and solve solid mechanics equations.
Contents	This course focuses on the computational tools used to study and improve electrochemical systems. It starts with an overview of essential applied computations such as applied linear algebra, multiscale analysis, Galerkin approximations, solid mechanics, and finite element methods, which are all crucial for designing electrochemical electrodes. A significant part of the course is dedicated to using finite element analysis. Through practical exercises and sessions, students will develop programming skills and work with open-source modeling software. These hands-on activities will cover electrode image analysis, transport phenomena, mechanics, and electrode optimization.
Requirements	Required: Individual alignment modules.
Availability frequency / Duration	Every summer semester / 1 semester
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Written or oral examination (1/2) and presentation (1/2)
Student work input in hours	Lecture: 30 hours; preparation and follow-up: 15 hours Exercises: 15 hours; preparation and follow-up: 15 hours Practical training: 15 hours; preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Data Analysis in Energy and Climate**
Responsibility	Junior Professorship for Information Systems Research, in particular on Connected Energy Storage
Type of course	Seminar (3 SWS)
Desired learning outcomes	The students are familiar with retrieving, reading, analyzing, and visualizing energy and climate related data using Python. They will be able to leverage the data in econometric analyses and modelling applications.
Contents	This class provides an introduction to handling real world data in the context of energy and climate-related research, specifically geospatial data in electricity markets and electric mobility. The class covers how to access different data sources through means such as APIs or webcrawling. The subsequent focus lies on geospatial data, such as relevant municipality-level socioeconomic data, photovoltaics systems, or electric vehicle charging stations. We will introduce the concepts and tools in manipulating, visualizing, and utilizing geodata with the geo-pandas package in Python. We will further use the data in econometric analyses and modelling applications.
Requirements	Basic programming skills (e.g. Python) are recommended
Availability frequency / Duration	Summer semester 2025, from winter semester 2025/26 every winter semester / 1 semester The module is offered as a block course.
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Presentation (2/5) and contribution (paper, 20 pages, 3/5)
Student work input in hours	Seminar: 30 hours Preparation and follow-up of the seminar (incl. presentation): 60 hours Paper writing: 60 hours

Module title	Economic Principles of Electricity Markets
Responsibility	Junior professorship of Information Systems Research, in particular on Energy Storage Networks
Type of course	Lecture (2 SWS) and tutorial (2 SWS)
Desired learning outcomes	The students know the fundamentals of electricity markets and can model the underlying economic mechanisms as well as interpret optimization studies used for economic policy.
Contents	This class provides an introduction to the economic principles of electricity markets. We first discuss wholesale markets and how the interaction of supply and demand determines time- and location-dependent electricity prices. We further study the German market as well as other selected international markets to understand how market design choices impact price building as well as the integration of renewable energies. We finally learn how electricity markets can be modelled using common programming languages and how such models can be used to study policy-relevant questions, such as the phase-out of nuclear power plants or the introduction of a CO2 price. The lecture will further include a discussion of other topics relevant to the decarbonization of electricity, such as different tools for CO2 pricing, policies supporting renewable energies, and demand-side measures.
Requirements	Basic programming skills, such as taught in "Fundamentals of Scientific Programming" are recommended but not required
Availability frequency/ Duration	Every winter semester / 1 semester
Recommended semester	2nd/ 3rd course semester
Language of instruction	English
ECTS credit points	5 ECTS
Module testing	Written or oral examination (1/2) and contribution (paper, 1/2)
Student work input in hours	Lecture: 30 hours Preparation and self-study: 30 hours Tutorials: 30 hours Paper writing: 60 hours

Module title	**Electrical Energy Systems**
Responsibility	Chair of Electrical Energy Systems
Type of course	Lecture (2 SWS), Exercises (2 SWS) and Practical training (1 SWS)
Desired learning outcomes	Expertise and skills in the operation and optimization of energy systems
Contents	• Description and modelling of electrical power systems • The control and operation management of power systems • The methods of energy management • Fundamentals of optimization of power systems under the constraints of economy, efficiency, reliability, longevity and security of supply • The methods of optimization include gradient-based and gradient-free methods • Constrained optimization methods and globally optimal methods. • Electric power systems covered from distributed electrochemical storage to power plants, distribution grids, microgrids, and electric transmission systems • Application and deepening of the knowledge by means of exercise examples
Requirements	Module Battery System Technology 1
Availability frequency / Duration	Every summer semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German / English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours Exercise: 30 hours; Preparation and follow-up: 30 hours Practical training: 15 hours Exam preparation: 30 hours

Module title	**Electrocatalysis and Electrochemical Process Engineering**
Responsibility	Chair of Electrochemical Process Engineering
Type of course	Lecture (2 SWS), Seminar (1 SWS)
Desired learning outcomes	The students actively repeat the basics of electrochemistry and discuss the principles of electrocatalysis in comparison to heterogeneous catalysis. They learn about the design of electrochemical reactors and deepen their knowledge of transport processes, especially in porous layers. Using current examples from fuel cells, electrolysis, etc., the students will be able to describe complex electrochemical systems in detail and design them for later application.
Contents	• Electrochemical basics • Electrochemistry in equilibrium: double layer and Nernst • Electrode kinetics: Butler-Volmer, Kouteky-Levich • Principles of electrocatalysis • Volcano curves and determinants • Design of electrochemical reactors • Transport processes Current examples: Fuel cells, electrolysis, CO_2 electroreduction
Requirements	Basic knowledge of chemical kinetics, catalysis, materials design and characterization
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	2nd / 3rd semester
Language of instruction	German / English
ECTS credit points	5 LP
Module testing	Written or oral (20 min.) examination (2/3) and seminar presentation (15 min., 1/3)
Student work input in hours	Lecture, preparation and follow-up: 45 hours Seminar, preparation and follow-up: 45 hours Preparation of exam and seminar presentation: 60 hours

Module title	**Electrode Design of Electrochemical Energy Storage**
Responsibility	Chair of Electrode Design for Electrochemical Energy Systems
Type of course	Lecture (2 SWS) and Exercises (2 SWS)
Desired learning outcomes	At the end of the course, the students will be able to: • Compute essential properties relevant to electrode design. • Apply principles of material design to create effective battery electrodes. • Analyse battery cell production equipment, processing flows and methodologies. • Understand the assembly processes for real-world electrode fabrication.
Contents	This course offers a comprehensive examination of the principles that form the foundation for battery electrode design within various battery technologies. It begins with an introduction to the physics of rechargeable batteries, with a special focus on electrochemical cells and their functionality. This part of the course elucidates the thermodynamics of batteries and guides students in calculating key properties pertinent to electrode design, such as gravimetric and volumetric capacities, electromotive force, and maximum energy content. The course then transitions into exploring the dynamics of various processes, followed by a detailed discussion on design principles. Emphasizing the fundamental physical and chemical principles and incorporating modeling techniques, this section provides an understanding of electrode construction. The subsequent modules examine battery cell production equipment, processing flows, and methodologies that are tailored specifically for creating functional electrodes. This provides students with an all-encompassing perspective of real-world electrode fabrication, ensuring a well-rounded and applied understanding of the subject matter.
Requirements	Required: individual alignment modules.
Availability frequency / Duration	Every winter semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	written or oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Exercises: 30 hours; Preparation and follow-up: 30 hours Exam preparation: 30 hours

Module title	**Functional Devices and Technologies for Automotive and Mechatronics**
Responsibility	Chair of Functional Materials
Type of course	Lecture (3 SWS), Exercises (1 SWS) and Practical training (1 SWS)
Desired learning outcomes	• Overview of electrical technology and electronic components • Assessment skills for electrical technology and components and their technologies, as required for an engineer working in the automotive or supplier industry, with special consideration of material-related and process-related aspects
Contents	• Electrical technology, as required for an engineer working in the automotive or supplier industry • Special emphasis is placed on assembly and connection technology • Production and technology of electronic devices and components incl. Applications and parameters • Practical training on electrical engineering and component characterisation
Requirements	Individual alignment modules, recommended: Bachelor's degree in engineering science or equivalent.
Availability frequency / Duration	Every summer semester / 1 semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German
ECTS credit points	5 LP
Module testing	Oral examination
Student work input in hours	Lecture and exercises: 60 hours; Preparation and follow-up 30 hours Practical training: 15 hours; preparation and follow-up: 15 hours Exam preparation: 30 hours

Module title	**Modelling and Simulation of Electrochemical Energy Storage Systems**
Responsibility	Chair of Electrical Energy Systems
Type of course	Lecture (2 SWS) and Practical Training (2 SWS)
Desired learning outcomes	• Knowledge of the fundamentals and theories of the processes taking place in an electro-chemical storage systems; • Acquisition of competences in the methods and approaches of modelling and simulation of electrochemical storage devices.
Contents	• The theory of the fundamentals of electrochemical storage: electrochemical potential and thermodynamics, mass transport in electrolyte and electrode, double layer and electrode kinetics. • The methods of modelling and simulation of electrochemical storage in theory and practice: modelling concepts, model classes. • Modelling approaches are dealt with for the following topics: concentrated equivalent circuit models, spatially discretised lead models, Newman model for the simplification of porous structures, finite element method for the solution of partial differential equations, thermal modelling, electrochemical impedance models (EIS) with an in-depth look at distributed relaxation times (DRT). • Finally, there is an outlook on further modelling approaches such as Gaussian process models or neural networks as well as a classification and evaluation of the models dealt with.
Requirements	Module Battery Systems Technology 1
Availability frequency / Duration	Every winter semester / 1 Semester
Recommended semester	2nd / 3rd course semester
Language of instruction	German
ECTS credit points	5 LP
Module testing	Written or oral examination (3/5) and contribution (practical training report, 2/5)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 15 hours, Tests during practical training (programming and documentation): 30 hours; Preparation and follow-up of tests: 45 hours Exam preparation: 30 hours

Module title	**Solid State Materials Characterization**
Responsibility	Chair of Electrochemical Process Engineering
Type of course	Lecture (2 SWS) and Practical training (2 SWS)
Desired learning outcomes	The objective is to acquire core competences in the field of solid-state materials characterization. The students will gain an overview of spectroscopy, microscopy, and diffraction methods commonly used to analyse battery materials ex-situ, in-situ and operando. They will learn about different set-ups, lateral and depth resolution, get to know the working principles and the respective methodical constraints. The students will be able to utilise this new knowledge to select the most promising method or combination of techniques.
Contents	The lecture covers the following topics: overview and classification of characterization techniques, general experimental set-ups, sources, monochromators, detectors. After the general introduction, each further lecture will highlight a specific method, its working principle, advantages and constraints. X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), electron microscopy (SEM, TEM) and other relevant techniques will be covered in depth. This will allow the students to pick the most suited methodical approach for several practical and battery-related examples. In the practical course, students deepen their knowledge of the various methods by applying a combination of different techniques available at the chair under supervision in order to characterize a battery material they have produced or an electrode they have processed themselves.
Requirements	Recommended: Alignment modules Materials Science and Physical Chemistry.
Availability frequency / Duration	Every summer semester / 1 Semester
Recommended semester	2^{nd} / 3^{rd} course semester
Language of instruction	German
ECTS credit points	5 LP
Module testing	Written examination, mandatory practical training (incl. submission of a written homework assessment, confirmed as passed)
Student work input in hours	Lecture: 30 hours; Preparation and follow-up: 30 hours Practical training: 30 hours; written homework assessment: 15 hours, Preparation and follow-up: 15 hours Exam preparation: 30 hours

Module title	**Systems Engineering and Requirements Engineering**
Responsibility	Chair of Systems Engineering for Electrochemical Energy Storage
Type of course	Lecture (2 SWS) and Exercise (2 SWS)
Desired learning outcomes	By the end of this course, students will be able to: • Explain the tasks and objectives of SE and the role of the SE engineer. • Explain phases in the system life cycle and different life cycle models • Identify system interfaces and meaningful system limits • Identify stakeholders and determine requirements for a system • Formulate good natural language requirements specifications themselves and evaluate existing ones • Create simple system models using SysML and understand more complex diagrams • Describe the behaviour and architecture of a system using SysML • Apply methods for solution space expansion • Apply methods and techniques for evaluating solution alternatives
Contents	Basics of Systems Engineering (SE): system definition and delimitation, goals and tasks in SE, phases in SE and different life cycle models; importance of good requirements, requirements elicitation, formulation and management; methods and techniques for expanding the solution space; evaluating variants and making decisions; Model-based SE with SysML: introduction and application of the different diagrams; verification and validation in the system development process.
Requirements	none
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd or 3rd course semester
Language of instruction	In winter semester: English In summer semester: German
ECTS credit points	5 LP
Module testing	oral examination
Student work input in hours	Lecture: 30 hours; Preparation and follow up: 25 hours Exercises: 30 hours; Preparation and follow up: 15 hours Exam preparation: 50 hours