UNIVERSITÄT BAYREUTH

Module Handbook

Battery Materials and Technology (M.Sc.)

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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. Especially because the interdisciplinary nature of battery research and technology, which in addition to the basics of chemistry and material research, also requires good knowledge of electrical engineering and applied thermodynamics; 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 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, and to establish a broad and mostly independent focus in specific 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 (T), seminars (S) and internships (P):

- **Lectures** (Abbreviation: V) deal with important topics of the respective field in a cohesive 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.

- **Internships** (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 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.

Typical exam types are written examinations, oral examinations, protocols, graded presentations or seminar papers (see §11 PSO).

Overview of the modules

Study outline

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

The students will be put on a common interdisciplinary basis by using the alignment modules in the adjustments / alignment module area.

The first joint interdisciplinary immersions are the Battery systems technology 1 and Battery materials 1 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 1 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. Accordingly, the corresponding modules take up a broad area in the first year of study.

The required elective modules A to C 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.

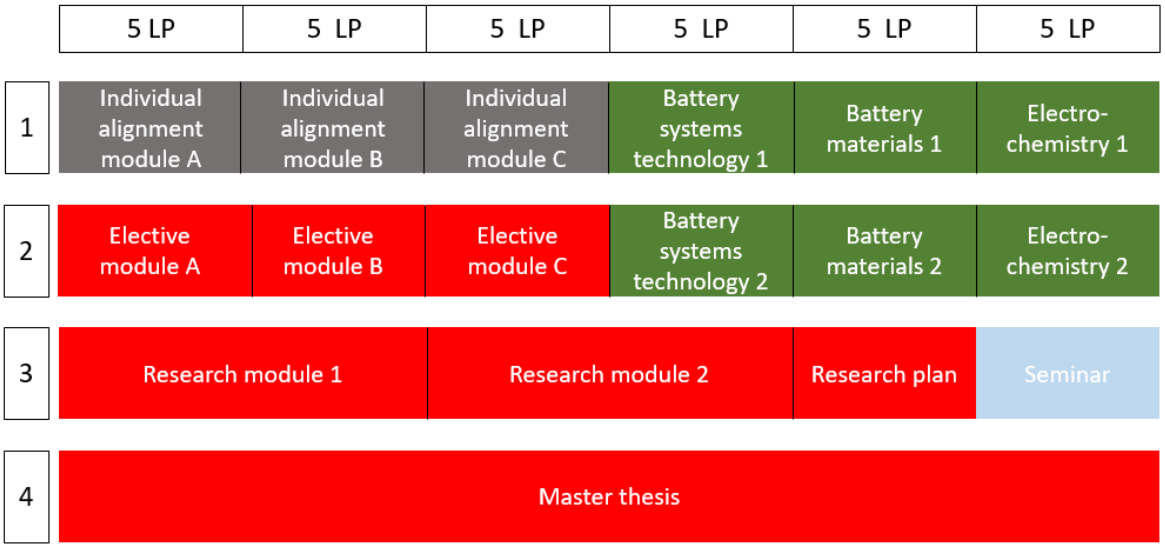
Further interdisciplinary studies follow, which are the modules Battery materials 2 and Electrochemistry 2, to deepen the knowledge in battery systems technology. Current scientific papers are presented in the seminar and discussed in front of a specialist audience.

The research modules allow students to creatively and critically apply their newly acquired knowledge to a current research topic and gain some insight into the respective departments at the Bayreuth Innovation Ecosystem, or alternatively to spend an academic period abroad.

The degree program concludes with the Master's thesis. It will be prepared based on a research plan.

Practical and international periods are possible within the regular study period.

Module structure



Module descriptions

Adjustment modules / alignment

The adjustment / 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.

The alignment modules are individually assigned from a catalogue of alignment modules. 3 alignment modules, totalling 15 LP (credits), are to be completed.

Sometimes other modules from courses of studies like mathematics, physics and computer science, biology, chemistry and geosciences as well as engineering sciences can be used as alignment modules with the approval of the Exam Commission. It should be noted, however, that these modules must not be already completed.

Individual alignment modules A, B and C.

Responsibility	Study programme moderator in conjunction with the corresponding educators
Type of course	Depending on the module selected from the module catalogue: Lecture / Exercise
Desired learning outcome	The students acquire basic knowledge specific to battery technology in areas in which they have not yet been sufficiently certified through their previous bachelor's degree, but which are considered necessary for their further studies.
Contents	The learning content relates to the basic knowledge of the modules selected in each case.
Admission prerequisite	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	Semester 1
Language of instruction	English
ECTS credit points	5 LP (credit points) per module
Course components In accordance with the aptitude assessment procedure, three events are specified from the following catalogue: • Principles of mathematics for electrochemical energy storage systems • Principles of physics for electrochemical energy storage systems • Principles of inorganic-chemistry for electrochemical energy storage • Principles of physico-chemistry for electrochemical energy storage • Macromolecular/organic chemistry for electrochemical energy storage systems • Inorganic-chemical principles of electrochemical energy storage systems • Principles of mechanical engineering for electrochemical energy storage systems • Principles of material science for electrochemical energy storage systems	
Module testing	Written exam
Student work effort in hours per module	Attendance time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Mandatory modules

The research module and the master thesis must be related to the ‘battery’ topic. The subject will be selected by a professorship who is involved in the course of study.

The Research Modules 1 and 2 can be carried out at all professorships participating in the study program. Two different modules are not to be carried out in the same research group. A research module can be carried out externally or even abroad.

Battery systems technology 1

Responsibility	Participating professorships
Type of course	Lecture (V) and Exercises (Ü) and Internship (P)
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 characterisation 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.
Eligibility requirements	None
Offer frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Course components 2V+1Ü+1P	
Module testing	Written / oral examinations
Student Student work input in hours	Lecture: 30 hours Preparation and follow-up: 15 h Exercises: 15 hours Preparation and follow-up: 30 h Internship: 30 h Exam preparation: 30 h

Battery systems technology 2

Responsibility	Participating professorships
Type of course	Lecture (V) and Seminar (S) and Exercises (Ü)
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.
Admission requirements	Recommended: Adjustment modules A to C.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd course semester
Language of instruction	English
ECTS credit points	5 LP
Course components 2 V + 1 Ü + 1 S	
Module testing	Written / oral examinations
Student Student work input in hours	Lecture: 30 hours Preparation and follow-up: 15 h Exercises: 15 hours Preparation and follow-up: 30 h Seminar: 15 hours preparation and follow-up: 15 h Exam preparation: 30 h

Battery materials 1

Responsibility	Participating professorships
Type of course	Lecture (V) and Internship (P), if necessary, Exercises (Ü)
Desired learning outcomes	Interdisciplinary acquisition of competence in the field of battery materials
Contents	Battery concepts, fundamentals of Solid-State Chemistry, material-chemical concepts in the field of electrode processes, cathode materials, anode materials, separators and ion line
Admission requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Course components 2 V + 2 P	
Module testing	Written / oral examinations
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Battery materials 2

Responsibility	Participating professorships
Type of course	Lecture (V) and Internship (P) and Seminar (S)s
Desired learning outcomes	Concepts of competence in the field of battery materials
Contents	Modern battery concepts especially with regard to post-Li batteries, material chemistry with regard to efficiency and safety in Li-batteries and related systems, electrochemical characterisation methods, solid body analysis, Operando analysis
Admission requirements	Recommended: Adjustment modules A to C.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd course semester
Language of instruction	German
ECTS credit points	5 LP
Course components 2V +1P +1S	
Module testing	Written / oral examinations
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Electrochemistry 1

Responsibility	Participating professorships
Type of course	Lecture (V) and Exercises (Ü) and Internship (P)
Desired learning outcomes	Acquiring competence in the field of electrochemical principles and measuring and instrumentation
Contents	Electrodes, electrolyte, electrochemical voltage series, reference electrodes, Nernst equation, relationship between electrochemistry and chemical thermodynamics, potentiostat, IR-drop, diffusion potential, electrochemical double layer, electrochemical kinetics, Butler-Volmer equation, Tafel plot, electrochemical measuring and instrumentation, cyclic voltammetry, impedance spectroscopy.
Admission requirements	None
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	1st course semester
Language of instruction	English
ECTS credit points	5 LP
Course components 2V + 1Ü +1P	
Module testing	Written / oral examinations
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Electrochemistry 2

Responsibility	Participating professorships
Type of course	Lecture (V) and Internship (P) and Seminar (S)
Desired learning outcomes	Acquiring competence in the field of electrochemical principles for electrochemical energy storage
Contents	Characteristics of batteries and rechargeable batteries, capacity, energy and power density, voltage with/without load, loss mechanisms, discharge curves, final discharge voltage, cell systems and their structure, electrode materials, super-capacitor, redox flow battery
Admission requirements	Recommended: Adjustment modules A to C.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	2nd course semester
Language of instruction	English
ECTS credit points	5 LP
Course components 2V +1P +1S	
Module testing	Written / oral examinations
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Seminar

Responsibility	Moderator for programme of studies
Type of course	Seminar (S)
Desired learning outcomes	Presentation and discussion of recent scientific works in front of a specialist audience
Contents	Current scientific works from the field of battery technology are presented by the students and are placed into an overall scientific context. The seminar presentation is followed by an academic discussion.
Admission 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	German or English
ECTS credit points	5 LP
Course components Before the start of the event, a list of acceptable seminar topics is published, from which students can select a topic. Each seminar lecture is supervised by a professor who is involved in the course of study. There is a duty to attend the entire event to ensure that the learning objective can be achieved.	
Module testing	Graded seminar paper
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Research module 1 and 2

Responsibility	Chairs or professorships involved in the course of study
Type of course	Practical research in a work group and written report of the results as well as presentation to the specialist audience
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.
Admission prerequisite	Successful completion of the individual adjustment modules and the mandatory modules is recommended.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	3rd course semester
Language of instruction	English
ECTS credit points	10 LP (credit points) per module
Module testing	Graded protocol and graded presentation
Student work effort in hours per module	Practical work and evaluation = 200h, preparation, writing and presentation = 25h+ 50h +25 h. Total: 300 h

Research plan

Responsibility	Chairs or professorships involved in the course of study
Type of course	Written report and presenting the results to a specialist audience
Desired learning outcomes	This module will teach how to prepare a scientific research work, in particular with regard to the current state of research, taking into account the scientific literature as well as appropriate time and experiment planning.
Contents	An up-to-date literature outline should be drawn up before any experimental work is started, and the essential questions concerning the planned research are presented in relation to each other. 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. A presentation and subsequent discussions will again serve to hone presentation skills and facilitate comprehensive feedback on the intended research.
Admission prerequisite	The successful completion of the individual adjustment modules and the mandatory modules is recommended.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	3rd course semester
Language of instruction	English
ECTS credit points	5 LP
Module testing	Graded protocol and graded presentation
Student Student work input in hours	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h

Master 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 report on a current battery-related topic
Admission prerequisite	Advanced study ability; passing exams for at least 40 LP credits (see examination and study regulations for this and other regulations).
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	4th course semester
Language	English or German
ECTS credit points	30 LP
Course components	
Master thesis	
Module testing	Dissertation
Student Student work input in hours	Research, evaluation and written elaboration on the master thesis = 900 h.

Compulsory elective modules

There are 3 compulsory electives to be completed, ea. 5 LP (credits). Two modules from the elective field of 'natural sciences' and one module from the field of 'engineering sciences' are to be selected.

The compulsory elective modules are to be chosen from a list of elective modules.

Elective module A, B and C

Responsibility	Study programme moderator in conjunction with the corresponding educators
Type of course	Depending on the module selected from the module catalogue: Lecture (V) / Seminar (S) / Exercise (Ü)
Desired learning outcomes	Individual competence broadening; see individual description of available modules
Contents	Students select individual modules from a continuously updated list. The modules allow you to individually broaden your knowledge along diverse technological challenges of the entire value-added chain of batteries.
Admission prerequisite	Check the announcements of the individual modules.
Availability frequency / Duration	Every semester / 1 semester
Recommended semester	Semester 2
Language of instruction	English
ECTS credit points	5 LP (credit points) per module

Course components

The compulsory electives to be selected, each with 5 LP credits, come from a regularly updated list that is published in time before the beginning of the semester. They are offered by the following professorships:

Engineering sciences elective
[You must select one compulsory elective module]

Electronics of electrical energy storage
Systems engineering of electrical energy storage
Electrode design of electrochemical energy storage
Cell design of electrochemical energy storage
Electrical energy systems
Functional materials

Material process engineering Methodology of battery management Business informatics and sustainable IT management <u>Natural science elective</u> [You must choose two compulsory elective modules] Electrochemistry Operando analysis of electrochemical energy storage Inorganic active materials for electrochemical energy storage Polymer materials for electrochemical storage Applied chemistry: Sustainability and material cycles Physical chemistry I-III. Inorganic chemistry I-III. Macromolecular chemistry I-III. Theoretical physics	
Module testing	Written / oral examinations
Student work effort in hours per module	Active time: 30 h Preparation and follow-up: 30 h Exam preparation: 90 h