UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Faculty of Chemistry and Earth Sciences &

Max Planck School *Matter to Life*

Module Handbook

Matter to Life, Master of Science, M.Sc.

Referring to the Examination Rules and Regulations of 15.01.2019

Introduction date:	Winter semester 2020/2021
Standard period of study	4 Semester
Number of course credits:	120 CP
Number of university places:	10
Form of study:	full time
Master study course:	consecutive, interdisciplinary
Language:	English

Table of Content

Motivation

Living organisms – being it single cells, organs, or complete humans or animals – consist of a system of finely tuned interacting components. They range in size and complexity from molecules to organs, tissue, bones, up to the nervous system. An organism is a complicated machine that burns fuel (generating free energy) to stay away from the thermodynamic equilibrium where no driving forces exist and the energy and entropy terms for ΔG are balanced (= death). A steam locomotive burns coal (chemistry), to move a piston which transfers its energy to generate movement (physics). Attach some train wagons and build a track, and it becomes a system which can perform work by carrying cargo and passengers.

How would one replicate such a system without any construction plan?

It would require taking the entire system apart, step-by-step, down to the smallest components in order to understand the function of the parts and their material composition, in other words: reverse engineering. Once the construction plan and the function of the individual components are understood, the original can be replicated or, even better, it can be improved.

The same reverse engineering approach is applied routinely to cells, tissue, organs, bones and the nervous system: biomedical research tries to understand the function of the components of a living organism to develop repair strategies that ensure that the whole system does not collapse simply because one part fails. To understand functions and mechanisms in an engineering sense, the system has to be analyzed quantitatively covering all relevant length scales – from the macroscopic, mesoscopic, down to the molecular scale – and then be described by theory and modeling. Such a "top-down" approach is needed to untangle and quantify the complex interactions in order to get an engineering construction plan.

The Max Planck School ***MATTER* to *LIFE*** aims to go beyond identifying and analyzing building blocks for engineering life. The School will foster open-mindedness and multidisciplinary collaborations; it will educate a new generation of scientists able to elucidate questions such as

☐ **what is life exactly?**

☐ **how can life be quantitatively described?**

☐ **how can life-like systems be engineered?**

This will be achieved through intense mentoring of the students by an exceptional group of scientist and scholars, and by access to the most advanced instruments for reverse engineering of living systems; students will learn how to operate these, how to interpret the data, and how to extract the information necessary for making a blueprint of life.

Hence, the curriculum of the School has been developed to overcome the traditional borderlines which have grown historically between disciplines. It addresses the roots of life in chemistry and physics, which form the basis for understanding life and provide the means to engineer life-related processes.

Specific Features of the Study Course

Students of this study course are part of the Max Planck School *Matter to Life*. The School brings together internationally acclaimed scientists from different locations working on a specific topic. It offers research-oriented studies with individual mentoring and diverse laboratory places in an interdisciplinary community. The small number of university places guarantees an optimum ratio between students and teachers, and enables individual, personalized mentoring tailored to meet the interests and needs of the student.

The Study Course *Matter to Life* uses the "inverted classroom" teaching format. Students cover the lecture material first on their own based on the teaching materials provided. They do so on their own terms, individually choosing time, location and learning speed. In the following in-class lecture, problems and open questions will be discussed. Case studies or problems are jointly solved through active participation of the students and serve to deepen their knowledge.

Multidisciplinary Teaching

The Study Course *Matter to Life* with a Molecular Systems Chemistry focus provides students with a multidisciplinary education integrating, in addition to a profound chemical education, contents from Physics, Molecular Systems and Engineering, and the Life Sciences.
To ensure this interdisciplinarity the Master Study Course *Matter to Life* will focus on the following scientific topics:

- Basic Physical Chemistry of Life
- Understanding Chemistry and Physics of Life
- Quantitative Analysis of Life
- Hierarchical assemblies of molecular and nanoscopic units as basis for life-like materials

Qualification Objectives and Overview of the Study Course

Preamble: Qualification Objectives of the University Heidelberg

Following its mission statement and its constitution, the University of Heidelberg pursues in its degree courses disciplinary, interdisciplinary, and professional objectives for a comprehensive academic education and subsequent professional career of its students. The resulting competence profile is included in the module handbooks as a valid qualification profile for all disciplines and is implemented by the specific qualification objectives, curricula, and modules of the individual study courses:

- development of subject-specific competence with a pronounced research orientation;
- development of transdisciplinary competence for dialogue;
- development of personal and social competence;
- promoting the willingness to assume social responsibility on the basis of the acquired competencies.

Qualification Objectives of the Master Study Course *Matter to Life*

The Master Study Course is heavily research-oriented and encourages students to think and learn autonomously. It draws upon different experiences in the Bachelor Study Course and covers interdisciplinary scientific issues.

Upon successful completion of the Master Study Course, *Matter to Life* students will have acquired a profound specialist knowledge of the fundamental chemical-physical principles of life and are able to scientifically describe, analyze, evaluate, and successfully solve challenging problems and tasks in this interdisciplinary area. They are able to plan and independently perform experimental or theoretical studies as well as scientifically document, interpret, and present their results in a convincing manner.

Successful graduates of the Master Study Course *Matter to Life* receive an education that will qualify them for a research-related professional career in interdisciplinary, innovative scientific fields. They are able to contribute scientific knowledge to formulate and solve complex problems and tasks at universities and other research institutions as well as in industry. Furthermore, they have experience communicating their expertise in a multidisciplinary environment. They are able to acquaint themselves with new topics and the operation of advanced scientific equipment.
They also have the skills to construct life-like molecular systems and materials, and to describe them theoretically. Furthermore, they are able to apply chemical-physical principles to describe the behavior of complex materials.

They have a profound understanding of applications, compounds, materials, and methods in a chemical-biological context and are aware of potential limitations and risks. They are able to responsibly apply their knowledge taking into account safety-related, ecological, ethic, and economic requirements.
They can actively shape public opinion with regard to scientific issues. They are able to disseminate their own research results and explain complex facts in English through oral or written presentations.

Successful graduates of the Master Study Course *Matter to Life* have the academic qualification for a doctorate in the Max Planck School *Matter to Life* (pass mark higher/equal 2).

Curriculum *Matter to Life* at the University of Heidelberg

with a Molecular Systems Chemistry and Engineering focus

Compulsory Elective Modules(100 CP)

Module Name	Course name	Designation	Taught Courses	Semester hours	Recom. Sem.	CP
Basic Physical Chemistry of Life	Physical Chemistry of Life	MtL_PCL_1	Lecture	3	1	4
	Data Science and Simulations	MtL_PCL_2	Lecture with Practical Computer Training	3	1	4
Quantitative Analysis of the Chemistry of Life	Quantitative Analysis	MtL_QAL 1	Lecture with Practical Training	2	1	2
	Synthetic Chemistry	MtL_QAL 2	Lecture	4	1	6
Physics of Complex Systems and Biophysics of Life	Physics of Complex Systems	MtL_CPL 1	Lecture with Problem Class	6	1	6
	Synthetic Biology	MtL_CPL 2	Lecture	2	1	5
Ethics in Synthetic Biology	Ethics in Synthetic Biology	MtL_ESB	Lecture	2	1	3
Final Oral Exam	Final Oral Exam	MtL_MP	Master Exam	-	2	10
Lab Rotation	Lab Rotation	MtL_LR	Research Internship	-	3	30
Master Thesis	Master Thesis	MtL_MA	Master Thesis	-	4	30

Elective Modules (20 CP)

We offer elective modules in the area of Molecular Systems Chemistry and Molecular Systems Engineering at the University of Heidelberg. These include the following courses:

Module Name	Course Name	Designation	Taught Courses	Semester hours	Recom. Sem.	CP
Molecular Systems Chemistry (MtL_MSC)	Macromolecular Structures and Functions	MtL_MSC_1	Lecture with Practical Training	4	2	5
	Chemical Biology	MtL_MSC_2	Lecture with Practical Training	2	2	4
	Bioconjugation & Imaging Chemistry	MtL_MSC_3	Lecture	2	2	3
Molecular Systems	Genome Engineering	MtL_MSE_1	Lecture with Practical Training	2	2	4

Engineering (MtL_MSE)	Synthetic Cells & Virology	MtL_MSE_2	Lecture with Practical Training	2	2	4

Explanation for cumulative exams:

The modules (MtL_PCL, MtL_QAL, MtL_CPL, MtL_MSC and MtL_MSE) in Matter to Life consist of various lectures approaching a core topic of *Matter to Life* from different directions. To the students, this has the advantage that the module structure already depicts the common thematic core and it therefore facilitates seeing the objectives of individual lectures from a macroscopic point of view. Moreover, every lecture is completed with an exam, which facilitates assessing the study load for the students and also distributes the examination burden more homogeneously.

In the Master Study Course *Matter to Life*, mainly the following forms of teaching and learning are used in the various courses:

Lecture: Lecture of teachers, preparation and follow-up work through independent study

Lectures in the inverted classroom:
Independent study of the subject matter and instructed in-depth study as well as application of the subject matter by the teacher during in-classroom lectures

Problem class/Tutorial:
Independent study, working on exercise sheets, active questions and discussions

Practical Training: Conducting and evaluating lab experiments, drafting experimental protocols

Course of Studies Plan

1st Semester	2nd Semester	3rd Semester	4th Semester
MtL_PCL (8 CP)	MtL_ MSC (12 CP)	MtL_LR (30 CP) MtL_MA (30 CP)	
MtL_QAL (8 CP)	MtL_MSE (8 CP)		
MtL_CPL (11 CP)	MtL_MP (10 LP)		
MtL_ESB (3 CP)			
30 CP	**30 CP**	**30 CP**	**30 CP**

Module Descriptions

Compulsory Elective Modules

Module MtL_PCL: Basic Physical Chemistry of Life
comprises Physical Chemistry of Life (MtL_PCL_1, 4 CP) and Data Science and Simulations (MtL_PCL_2, 4 CP).

Academic achievement and assessment tasks, pre-requisite for awarding credit points	Passing of the written exams of the individual lectures.
Calculation of module mark	The module mark is determined by the weighted and averaged written exams of the individual lectures of this module.

Lecture with Practical Computer Training MtL_PCL_1: Physical Chemistry (4 CP)

Content	The course provides knowledge of physical chemistry in the context of biological systems. It introduces advanced topics of physical chemistry of life: biochemical thermodynamics, macromolecular structures and interfacial chemistry. The course includes aspects of the physical chemistry of synthetic and natural macromolecules. Special focus is given to the kinetics of synthetic polymerization reactions and biopolymer synthesis as well as inter- and intramolecular interactions between macromolecules, whose molecular details and biological effects are discussed. With regard to interfaces, a significant aspect of this course is to demonstrate the importance of interfacial processes in chemistry and in relation to chemical engineering, cell biology, materials science and physics. Methods of surface modification, including specific functionalization and structuring strategies with an emphasis on self-organization processes are being introduced. Moreover, the characterization and role of possible intermolecular forces for interfacial interactions are being addressed. All concepts previously introduced will be connected in an extensive discussion about paradigmatic biological interfaces, such as lipid vesicles with an emphasis on their morphological complexity.
Learning objectives and skills	After successfully passing the module, the students will have obtained a fundamental understanding of advanced Physical Chemistry in the context of biological systems and are able to describe the concepts of macromolecular structures and interfacial chemistry. Furthermore, they are able to use concepts and methods of Physical Chemistry to propose possible research experiments to approach interdisciplinary research questions in the context of MtL.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester
Workload	4 CP (90 hours): 4 hours weekly preparation, 4 hours in-classroom lecture and 2 hours follow-up work + exam preparation
Duration of module	8 weeks
Teaching and exam language	English
Preparatory literature	To be announced

Lecture with Practical Computer Training MtL_PCL_2: Data Science and Simulations (4 CP)

Content	The course will cover computational methods that solve biological problems and guide the design of synthetic life-like systems on different scales. Methods will include both physics-based approaches such as particle-based atomistic and mesoscopic simulations as well as bioinformatic data-driven and machine learning techniques. Physics-based approaches include recent advances in Monte Carlo, Molecular Dynamics, and Brownian Dynamics simulations, and kinetic modelling. The course will teach data-driven techniques for the analysis of next-generation sequencing experiments, including transcriptome and single-cell analysis. The course will further introduce approaches in computer vision for the analysis of biological image data. An overarching focus will be multi-scale approaches that bridge the molecular with the mesoscopic and, eventually, the macroscopic scale. The topics will be motivated by examples from current research advances and challenges or recent literature or research of the faculty. For each of the topics, which serve as case studies and are centered around a specific subset of computational techniques, the relevant physical, chemical, or mathematical basis will be reviewed. Material describing the case study, the relevant background, and a code or software example will be handed out prior to the lecture. Hands-on practical trainings in a computer lab will complement the lectures. In the practical parts, depending on the complexity of the computational method, (pseudo)-code examples will be developed or complemented by critical parts within the course, or a scientific software will be applied to the problem of the case study in form of a tutorial. Applied methods including their range of application and potential pitfalls will be critically discussed.
Learning objectives and skills	After successfully passing the course, students will be able to select adequate computational methods and apply appropriate computer models and algorithms to complex biological problems as well as appreciate the respective validity range.
Pre-requisite for participation	Participation in MtL_PCL_1
Teaching format	Lecture partially in the Inverted Classroom and Practical Computer Training
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester
Workload	4 CP (90 hours): 4 hours weekly preparation, 4 hours in-classroom lecture and 2 hours follow-up work + exam preparation
Duration of module	8 weeks
Teaching and exam language	English

Preparatory literature	To be announced

Module MtL_QAL: Quantitative Analysis of Life
comprises lectures with practica: Quantitative Analysis Methods (MtL_QAL_1, 2 CP) and Synthetic Chemistry (MtL_QAL_2, 6 CP)

Academic achievement and assessment tasks, pre-requisite for awarding credit points	Successful completion of the written exams of the individual lectures
Calculation of module mark	The module mark is determined by the weighted and averaged written exams of the individual lectures of this module.

Lecture with Practical Training MtL_QAL_1: Quantitative Analysis Methods (2 CP)

Content	The course teaches students how state-of-the-art analytical methods can be used to elucidate the molecular mechanisms sustaining living systems. The importance of using a combination of techniques spanning all length scales of the objects (from molecular to mesoscopic) to be able to validate a hypothesis will be demonstrated with examples from recent literature. Emphasis will be placed on the need to generate reproducible and statistically significant data sets and to discuss the results in the context of past and recent relevant literature. The discussion of high-resolution optical microscopy (e.g. STED microscopy) and electron microscopy for analyzing biological systems will give students a detailed understanding of the complimentary use, and pros and cons of using light and electrons to analyze biological systems. The analytical possibilities offered by tunable high-energy radiation sources (synchrotron radiation and X-ray lasers) by combining imaging with spectroscopic methods to analyze chemical composition will be demonstrated. An important aspect will be how to identify and avoid artifacts and damage caused by sample preparation techniques and high-energy radiation. Mass and NMR spectroscopy will be taught jointly by a physical chemist and an organic chemist illustrating where disciplines meet. Diffraction and scattering as physical phenomena are the basic principles of physical optics relevant for the interaction of acoustic or electromagnetic waves with molecules and particles. The physical foundation of these phenomena will be taught and students will take part in hands-on practical courses in research labs to learn about the basic as well as modern technologies of scattering and diffraction. The module will also cover theoretical background and the methods to measure the dynamics and kinetics of biomolecular reactions and of time-dependent processes in living systems. The functioning and particular role of lasers in modern biological research will be presented. Different laser spectroscopy and scattering technologies will be discussed theoretically as well as in hands-on practical courses in top-of-the-notch research labs, with particular emphasis on time-dependent processes. The techniques and the underlying

	theory to measure fast and slow kinetics in biomolecular reactions are discussed with examples from the literature. We will cover the formal kinetic description of fast chemical and biomolecular reactions (enzyme kinetics), the statistical tools to analyze diffusion and convection data, and the experimental realization of kinetic measurements from stop-flow to pump-probe experiments. Again, emphasis will be placed on the need to generate reproducible and statistically significant data sets and to discuss the results in the context of past and recent relevant literature.
Learning objectives and skills	After successfully passing the module, the students will have obtained a fundamental understanding of analytical methods in the Natural Sciences. They will be able to formulate scientific hypotheses and design experiments to validate results taking into account reproducibility and statistical significance. They will be able to critically review analytical methods in publications.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom and Practical Training
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester
Workload	2 CP (60 hours): 1,5 hours preparation; 2 hours in-classroom lecture and 0,5 hours follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Lecture MtL_QAL_2: Synthetic Chemistry (6 CP)

Content	This course covers modern chemical reaction mechanisms. At first, knowledge and mechanistic understanding of important organic reactions are being revised and then, deeper knowledge in the field of organic chemistry is being taught. Thereby, not only fundamental organic reaction mechanisms, but also bioinorganic topics are being addressed.
Learning objectives and skills	After successfully passing the module, the students will have obtained a fundamental understanding of the reaction mechanisms of classical synthetic chemistry. They will be able to assess potential reactivity of individual chemical groups, thereby set up reaction mechanisms of chemical substances and have an idea of the experimental realization of these reactions. They will be able to understand reaction mechanisms and assess their impact.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom
Applicability of module	*Matter to Life* (Master)

Frequency	Yearly during the winter semester
Workload	6 CP (180 hours): 4 hours weekly preparation, 4 hours in-classroom lecture and 4 hours follow-up work Exam preparation
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Lecture MtL_CPL: Physics of Complex Systems and Biophysics of Life
comprises lectures Physics of Complex Systems (MtL_CPL_1, 6 CP) and Synthetic Biology (MTL_CPL_2, 5 CP).

Academic achievement and assessment tasks, pre-requisite for awarding credit points	Successful completion of the written exams of the individual lectures.
Calculation of module mark	The module mark is determined by the weighted and averaged written exams of the individual lectures of this module.

Lecture MtL CPL: Physics of Complex Systems (6 CP)

Content	The course teaches the fundamental concepts of the quantitative analysis of dynamic, complex, self-organizing systems applied to life processes. Furthermore, cutting-edge methods of complex systems to study biological problems will be discussed. The program will also present quantitative physical approaches and analysis techniques with regard to cell components and their interaction. An important aim is to overcome traditional barriers between the disciplines and expose students to most important concepts from physics, chemistry and biology, so that they can reach a common understanding of language, priorities and scientific culture in all areas, with the long-term goal of preparing students for increasingly interdisciplinary but also increasingly quantitative research in the life sciences. Research topics include physical aspects of biological dynamics, stochastic processes, reaction-diffusion processes, phase transformation, pattern formation and active processes.
Learning objectives and skills	After successfully passing the module, the students will be able to interdisciplinary describe and quantitatively model complex systems using the terminology of the respective disciplines.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom and Practice Group
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester

Workload	6 CP (150 hours): 4 hours weekly preparation, 4 hours in-classroom lectures and 2 hours follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Lecture MtL_CPL 2: Synthetic Biology (5 CP)

Content	The fields of specialization of this course include DNA technology, mechanics of biological systems, transport phenomena, biomimetics, tissue engineering and contents from applied computer science. The students have the opportunity to understand and develop projects which address the application of nanotechnologies to living organisms and lifelike systems. The students are given an understanding of modelling biological systems and bioinformatics. The course also provides a basis to understand and master bioengineering technologies for diagnosis and development of modern medical equipment. Modern analytical methods are being discussed complementary to *MtL_QAL_1: Quantitative Analysis Methods* in the context of bioengineering technologies. The students obtain a broad overview about the fundamentals of structural biology as well as methods and applications in the contemporary computational biology/chemistry. Essential structural properties of biomolecules (proteins, peptides, sugar, nucleic acids) that are found in nature in their variety of structures and functions are being discussed. The students get an overview of the fundamental concepts necessary to understand the effect of the three-dimensional structure of these biomolecules on their stability, dynamics, molecular recognition and functions. In addition, the students learn how to analyze biological questions from a structural point of view. They receive insights to the fundamentals necessary for the definition and development of structure-based rational engineering strategies for bio- and nanotechnology.
Learning objectives and skills	After successfully passing the module, the students will be able to design experiments for the quantitative analysis of three-dimensional structures of biomolecules in order to examine the stability, dynamics and molecular functions of biomolecules.
Pre-requisite for participation	
Teaching format	Lecture partially in the Inverted Classroom and Practice Group
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester
Workload	5 CP (150 hours): 4 hours weekly preparation; 4 hours in-classroom lectures (2 hours lecture, 2 hours practice group) and 2 hours follow-up work
Duration of module	1 Semester (lecture period)

Teaching and exam language	English
Preparatory literature	To be announced

Lecture MtL_ESB: Ethics in Synthetic Biology (3 CP)

Content	Firstly, the course will focus on biosafety issues, studying on the one hand how the application of results of synthetic biology might affect ecosystems. On the other hand, another focus will be on the possible misuse of scientific results. Such Dual Use Research Concerns arise because the publication of the different research results is in the interest of science but also of society. At the same time publishing e. g. the blueprints of "synthetic viruses" in scientific journals entails the danger that they might be used for adverse purposes. The second focus will be how ideas defining a culture, e. g. with respect to the relationship between natural and artificial or alive and not alive, change or are being questioned. It is of great importance to take such changes seriously as empirical studies about public opinion on synthetic biology have suggested that such cultural values play an important role in how the public responds to a new technology. Thirdly, synthetic biology also raises economic issues, especially in what manner the applied methods and their products can be patented or should they be patented at all. This issue is of special importance since the products of synthetic biology represent biological systems, the patentability of which is being debated in general. On the other hand, the hoped-for future products of synthetic biology such as a HIV vaccine are of such potential importance that it is being debated whether as many users as possible should have access to the research results. The fourth question deals with which social players should decide in which direction synthetic biology should develop. Currently, different forms of how the public can interact and participate in scientific developments are being discussed. The reason for this is that the public no longer just wants to be informed about scientific discoveries, but wants to get involved in some manner in science. This runs the gamut from citizen data collectors, monitors, assistant researchers to fully recognized citizen scientists. Synthetic biology has an especially close relationship with such forms of participation as it has been associated from its beginning with movements like do-it-yourself biology and biohacking. Scientists pay close attention to these ethical, legal, and social issues in the area of synthetic biology since they have realized that the further development of this discipline will not only be judged by its scientific results. Instead it depends to a large degree on with what society associates synthetic biology in the future and how it views this research field.
Learning objectives and skills	After successfully passing the module the students will have obtained a fundamental understanding of the relevant ethical issues. They can explain and discuss ethical problems.

Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom
Applicability of module	*Matter to Life* (Master)
Frequency	Yearly during the winter semester
Workload	2 CP (60 hours): 1,5 hours preparation; 2 hours in-classroom lectures and 0,5 hours follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Module MtL_LR: Research Internship (30 CP)

Content	The internship serves to expand upon and deepen the knowledge and experimental skills acquired in the study course. Its aim is to formulate a complex scientific problem, propose a research plan and summarize the conclusions. Students will learn how to operate complex modern equipment, how to carry out sophisticated experiments, and significantly expand upon the relevant theoretical basics.
Learning objectives and skills	After successfully completing the module the students have gained insight into doing scientific work, are able to handle complex equipment, and to independently carry out experiments. They have acquired the skills to independently plan and conduct experimental studies in scientific research and development, to interpret the results, and to present them orally and in writing. In particular, they are able to independently identify, obtain, and analyze information for scientific problem solving.
Pre-requisite for participation	Successful completion of all study-related exams and the final oral exam.
Teaching format	Practical Training
Applicability of module	*Matter to Life* (Master)
Academic achievement and assessment tasks	Written research report and presentation of the results in the corresponding group seminar.
Calculation of module mark	The module mark is determined by the assessment of the research report and the presentation with subsequent discussion in the corresponding group seminar.
Frequency	Yearly
Workload	30 CP (800 hours): 20 weeks laboratory Practical training + completion of the report and preparation of the presentation (900h)
Duration of module	1 Semester
Teaching and exam language	English
Preparatory literature	To be announced

Module MtL_MP: Final Oral Exam (10 CP)

Content	During the final oral exam, the candidates should be able to demonstrate that he/she is able to perceive the interrelations of the exam's subject matter and correlate specific problems with these interrelations. Furthermore, it will be assessed if the candidate has broad basic knowledge as well as specialist knowledge in specified topics of the subject matter.
Learning objectives and skills	Students will be able to perceive the overarching interrelations of the different courses and are able to formulate and discuss them in proper scientific terms.
Pre-requisite for participation	Successful completion of all modules of the Master Study Course *Matter to Life*, except for the research internship and the Master thesis.
Teaching format	not applicable
Applicability of module	*Matter to Life* (Master)
Academic achievement and assessment tasks	Oral exam
Calculation of module mark	The final oral exam will be conducted as a collegial exam by three examiners, who are actively engaged in teaching the study course. The candidate should be able to demonstrate a good overview of the subject and perception of the interrelations of the exam's subject matter as well as the contents of the individual modules. The exam lasts 60 minutes.
Frequency	yearly
Workload	18 CP (540 h; corresponds to the time for exam preparation)
Duration of module	2 Semesters (incl. preparatory time)
Teaching and exam language	English
Preparatory literature	To be announced

Module MtL_MA: Master Thesis (30 CP)

Content	A topic from a partial area of *Matter to Life* has to be pursued independently by scientific methods within the given period of time of the scientific work. The results will be put into writing in the Master thesis, which contains an abstract.
Learning objectives and skills	Students will be able to independently pursue a new (interdisciplinary) topic and perform the relevant literature search based on the knowledge they acquired during their studies. They will be able to apply current methods in chemistry and plan, set up, carry out, and document their experiments largely on their own. They can independently evaluate, put into writing, and critically discuss the results of their research.

Pre-requisite for participation	Successful completion of all study-related partial exams of the taught modules as well as of the final oral exam.
Teaching format	not applicable
Applicability of module	*Matter to Life* (Master)
Academic achievement and assessment tasks	The Master thesis will be evaluated by two examiners, one of them has to be a university professor. The supervisor of the thesis shall be the first examiner.
Calculation of module mark	The mark is determined by the arithmetic average of both assessments. If there is a difference of more than one mark, the Exam Board will determine the mark of the master thesis after hearing both examiners. The Board may consult a third examiner in such cases.
Frequency	Consecutive
Workload	30 CP (900 hours)
Duration of module	6 months. In exceptional cases, a 3-month extension may be granted upon request.
Teaching and exam language	English
Preparatory literature	Independent research of the literature related to the topic

Compulsory Elective Modules

Module MtL_MSC: Molecular Systems Chemistry
comprises the following courses:

- Macromolecular Structures and Functions (MtL_ MSCE_1, 5 CP)
- Chemical Biology (MtL_ MSCE_2, 4 CP)
- Bioconjugation & Imaging Chemistry (MtL_ MSCE_3, 3 CP)

Academic achievement and assessment tasks, pre-requisite for awarding credit points	Successful completion of written exams of the individual lectures.
Calculation of module mark	The module mark is determined by the written exams weighted according to the number of credit points per taught course.

Lecture with Practical Training MtL_ MSCE_1: Macromolecular Structures and Functions (5 CP)

Content	The course focuses on the great variety and diversification of macromolecular structures and their respective functionalities. It comprises technical knowledge on synthesis, on structural characterization, and on the engineering of functional properties bridging the field of synthetic polymers and their structure-property relations on the one hand and the chemistry of biomacromolecules on the other hand. Biomacromolecules are dealt with as advanced material components, e.g., in hybrid materials, but also as a paradigm for molecularly programmed complex and adaptive superstructures. The aim is to detail structural interrelations starting from monomer catenation, noncovalent bonding, and long range interactions (colloidal and entropic forces) to organization on the macromolecular and supramolecular level (from coils to globuli and other nanoobjects with defined secondary, tertiary and quarternary structure). The course provides a broad synthesis basis for macromolecules with a focus on sequence and molecular weight control as well as macromolecular stereochemistry: This comprises (i) controlled and living chain growth polymerization by ionic-, group transfer-, radical- and coordination complex insertion-mechanisms such as metathesis, metallocene, and Ziegler polymerization as well as (ii) step-growth synthesis including advanced polycondensation reactions (low band gap polymers, chain growth polycondensation, condensation-addition in water, fragment condensation, solid-phase synthesis, and cascade condensation like dendrimer synthesis). More specifically for biomacromolecules, synthesis techniques will include also enzymatic methods for the production of proteins and nuclei acids (PCR, rolling circle amplification, expressed protein ligation) complemented by biotechnology synthesis (recombinant protein expression). Emphasis will also be placed on methods that allow the conjugation of biobased and synthetic building blocks (click type reactions). Another focus is the structure property relations

	concerning self-assembly in aqueous solutions covering, helical structures, chain folding and structures of nucleic acids (A-, B-, Z-DNA) but also the next higher level of structural organization like globule and micelle formation, as well as structured network formation by covalent and reversible gelation processes and the assembly of blockcopolymers with more than two constituent polymer blocks. Beyond thermodynamic control, it will be demonstrated how assembly can be directed kinetically and by topological constraints, e.g., by the interplay between covalent and non-covalent chemistry by reversible coacervation, hydrophobic interaction and directed reversible bond formation. The course furthermore addresses physical characterization methods that are indispensable to monitor synthesis on all structural levels, starting from NMR-methods, optical and vibrational spectroscopies to fluorescence methods like FRET, as well as particle size and shape characterization by scattering methods and advanced microscopies (cryo-SEM and -TEM, scanning probe microscopy and advanced optical microscopy).
Learning objectives and skills	After successfully passing the module, students are able to describe various methods for the synthesis and analysis of natural and synthetic macromolecules and have obtained experience in the synthesis of macromolecules.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom with Practical Training
Applicability of module	Master (*Matter to Life*)
Frequency	Yearly during the summer semester
Workload	5 CP (150 hours): 4 hours weekly preparation, 4 hours in-classroom lectures and 2 hours follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Lecture with Practical Training MtL_ MSCE_2: Chemical Biology (4 CP)

Content	Chemical biology can be considered as the use of chemistry to probe living systems in situ. Specifically, it aims at developing tools to manipulate biological phenotypes as well as to visualize and quantify biochemical activities in vivo. The course will provide an introduction into contemporary chemical biology by discussing a selection of important papers. Each of these papers describes a technology or an approach that represents a conceptual advance and enables the investigation of a biological problem that could not be addressed with more traditional approaches. As chemical biological is a relative young and dynamic field, the papers to be discussed will be adapted each year. The following topics will be discussed in

	the class: (i) synthetic and genetically encoded probes; (ii) chemical biology of kinases; (iii) chemical labeling of proteins; (iv) semisynthesis of proteins; (v) expansion of the genetic code and unnatural amino acids, (vi) chemical optogenetics; (vii) chemical genetics; (viii) target deconvolution of bioactive molecules; (ix) activity-based protein profiling; (x) fluorescent probes. The course will require the students to read the underlying papers prior to the classes in order to be able to participate at the discussions.
Learning objectives and skills	The successful students are able to choose and apply tools from Chemistry, Cellular Biology, and Biophysics to study problems at a molecular level.
Pre-requisite for participation	Basic knowledge of Organic Chemistry, Biochemistry, and Molecular Biology
Teaching format	Lecture partially in the Inverted Classroom with Practical Training
Applicability of module	Master (*Matter to Life*)
Frequency	Yearly during the summer semester
Workload	4 CP (120 hours): 3 hours weekly preparation, 4 hours in-classroom lectures and 1 hour follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Lecture MtL_ MSCE_3: Bioconjugation & Imaging Chemistry (3 CP)

Content	The course will cover various types of molecular devices coupled to biological vectors, where the biological vectors will be responsible for transporting the devices to specific cells (e.g. selective labeling of tumor cells for imaging or therapy; vectors: peptides, antibodies, nanoparticles), and the types of molecular devices will include optical, magnetic and radiochemical probes. The synthesis of the molecular devices and methods for coupling of the devices to biological vectors will be briefly discussed. However, the main focus will be on the fundamental principles behind various probes (e.g. turn-on / turn-off optical sensors; paramagnetic probes for MRI imaging and structure determination, e.g. proteins in cells; radiopharmaceutical imaging and therapy). Many of these systems involve main group, transition metal and rare earth metal ions. The basic principles of metal ion selectivity, the prevention of transmetallation (chemical inertness under physiological conditions) will be discussed, and the theoretical basis of metal-based systems in relation to sensors and activators will be the main focus. The course will rely on and where necessary expand upon knowledge gained from the courses "Macromolecular Structures and Functions" as well as "Data Science".
Learning objectives and skills	After successfully passing the module, the students will have obtained a fundamental understanding of the synthesis and

	characterization of bioconjugates and their application as sensors and activators in biological systems to quantitatively analyze biological processes.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom
Applicability of module	Master (*Matter to Life*)
Frequency	Yearly during the summer semester
Workload	3 CP (90 hours): 3 hours weekly preparation, 2 hours in-classroom lectures and 1 hour follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced

Module MtL_MSC: Molecular Systems Engineering
comprises the following courses:

- Genome Engineering (MtL_MSE_1, 4 CP)
- Synthetic Cells & Virology (MtL_MSE_2, 4 CP)

Academic achievement and assessment tasks, pre-requisite for awarding credit points	Successful completion of the written exams of the individual lectures.
Calculation of module mark	The module mark is determined by the written exams weighted according to the number of credit points per lecture.

Lecture with Practical Training MtL_ MSE_1: Genome Engineering (4 CP)

Content	The ‘genome engineering’ course will provide an overview on the background and applications of genomic technologies to ‘read’ and ‘write’ genomes as a basis for synthetic biology. Content of the course will include an introduction into basic nucleic acid chemistry and function of DNA, as well as structural and functional aspects of genes and genome biology. Further topics will be on how information is encoded in the genome, methods to sequence genomes and recent breakthroughs that allow to sequence and assemble whole genome sequences. The course will then introduce methods to manipulate DNA, including DNA synthesis and the use of enzymatic methods for genetic engineering of simple and complex genome. The course will cover and discuss recent methodological developments in genome engineering, the discovery and development of CRISPR/Cas, its engineered versions that allow the knock-out of genes in genomes, the site-specific introduction of mutations and the replacements of whole genes or chromosomal regions. The course will also cover

	the application of genome engineering in biotechnology, diagnostics and therapy, in cell and tissue engineering and future applications of synthetic genomes. The course will discuss classic papers of major discoveries as well as cover most recent developments in genome engineering. Practicals will complement the topic with wet and dry lab expertise. Students will also discuss ethical, legal and societal implications of genome engineering. The module consists of inverted classroom lectures focused around "Case studies", which are examples from the recent literature and of the actual research of the faculty and will be handed out to the students prior to the discussion in class. The students study the material and are encouraged to propose experimental and/or theoretical strategies to solve the problem(s). The class meetings and tutorials then are intended to answer and discuss the questions that came up, deepen the understanding of the material, and develop investigative strategies which then can also can be tested in the exercises and laboratory classes
Learning objectives and skills	After successfully passing the module the students will have acquired a fundamental understanding of genome engineering and are able to critically read and review publications in this field. They will be able to apply genome engineering techniques.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom and Practical Training
Applicability of module	Master (*Matter to Life*)
Frequency	Yearly during the summer semester
Workload	4 CP (120 hours): 3 hours weekly preparation, 4 hour in-class lecture and 1 hour follow-up work
Duration of module	1 semester (lecture period)
Teaching and exam language	English
Preparatory Literature	To be announced

Lecture with Practical Training MtL_ MSE_2: Synthetic Cells & Virology (4 CP)

Content	The course will extend towards physical and chemical methods in modern synthetic biology to design and construct synthetic viruses with desired function and to construct synthetic cells and tissues which have life-like properties. State-of-the-art research topics will be discussed and will be a guide for the complete lecture. This will include advanced aspects of biofunctionalization, microfluidic and protein engineering approaches in order to assemble life-like machines, cells and tissues. The content will cover modern technologies based on light and microfluidic which regulate self-assembly in order to build-up life-like compartments. Immunology and virology and in particular its synthetic approaches are some of the most challenging topics of today's biomedical research. On the other hand, viruses are the smallest biological

	objects with the capacity to self-replicate in more complex systems. Thus engineering viruses or viral vectors with desired properties has already started to enter applied biomedical research and holds great potential for the future. On the other hand, viruses being foreign to their host have been crucial for the discovery of many cellular processes and accordingly appear to be optimal for constructing artificial cell-like systems that support part of their replication. Studying viral interactions with host cells and the immune system offers many examples where quantitative, interdisciplinary concepts with ample input from physics, chemistry and engineering resulted in break-through technologies and advances in biomedicine and clinical applications. Our approach aims to interfere into the life-cycle of cells by molecular or nanoscopic systems or even construct synthetic cells and viruses. This course series gives an overview of the most challenging and current research examples and will provide the scientific basis from chemistry, physics, molecular cell biology and biochemistry in order to understand the examples from synthetic virology. Hands-on practical courses will complement the topic with lab expertise in, e.g., microfluidics, viral vector design, DARPin technology or CRISPR/Cas-methods. The module consists of inverted classroom lectures focused around "Case studies", which are examples from the recent literature or the actual research of the faculty and will be handed out to the students prior to the discussion in class. The students study the material and are encouraged to propose experimental and/or theoretical strategies to solve the problem(s). The course meetings and tutorials then are intended to answer and discuss the questions that came up, deepen the understanding of the material, and develop investigative strategies which then can also can be tested in the exercises and laboratory classes Also the context of living versus non-living matter will be covered. Finally, the students will learn to design and construct chimeric antigen receptors (CARs, also known as chimeric immunoreceptors) aggs engineered receptors which graft an arbitrary specificity onto an immune cells (T cells) and are already entering clinical trials for certain diseases.
Learning objectives and skills	After successfully passing the module the students will have acquired an understanding of the synthesis and analysis of synthetic viruses and viral substructures (e. g. capsid coats and/or viral replication systems); furthermore, they have state-of-the knowledge of synthesis tools and technologies to generate such materials. They are able to design experiments to hierarchically assemble molecular and nanoscopic units as a basis for life-like materials.
Pre-requisite for participation	none
Teaching format	Lecture partially in the Inverted Classroom and Practical Training
Applicability of module	Master (*Matter to Life*)
Frequency	Yearly during the summer semester

Workload	4 CP (120 hours): 3 hours weekly preparation, 4 h in-class lecture and 1 hour follow-up work
Duration of module	1 Semester (lecture period)
Teaching and exam language	English
Preparatory literature	To be announced