



UNIVERSITÄT  
BAYREUTH

Elitenetzwerk  
Bayern



**Elite Study Program in Macromolecular Science**

**Start Module M050**

# **Modern Research Topics in Macromolecular Science**

**Faculty of the Elite Study Program**

**Winter term 2018/19**

The scope of the Start Module “*Modern Research Topics in Macromolecular Science*” is to introduce the students, coming from different backgrounds, to various facets of the broad and interdisciplinary field of Macromolecular Science. It is intended that the students will get a basic understanding of underlying concepts, terminology and methodologies in the individual subfields of Macromolecular Science. The offered topics cover the fields macromolecular chemistry, colloidal chemistry, biopolymers, biochemistry, polymer physics, biophysics, polymer technology, polymer engineering, electronic and optical devices, advanced characterization methods, and theory and simulation of macromolecules.

In the module 13 topics are offered, compiled in four blocks A, B, C and D. Each student has to select 8 topics. To meet the interdisciplinary intention of the module at least one topic of each block has to be selected. Each topic has a length of about 8 to 10 hours and includes lectures, seminars and laboratory tours. In addition the students will have a tour and introduction to the research facilities.

### **A1: Design of supramolecular architectures for functional materials**

*Hans-Werner Schmidt, Macromolecular Chemistry*

A major challenge in polymer science, with respect to novel functional and even multifunctional materials, is the understanding and control of hierarchical structured supramolecular polymers and nano-objects created by (macro)molecular self-assembly. Such complex self-assembled structures will provide constant progress in materials science and play a key role for innovative solutions. Our goal is to fine-tune specific and complex functionality across all length scales (nano to macro) through molecular design and novel hierarchically structured systems. In this context, we explored in the past years the design and structure-property relations of molecules capable to self-assemble into supramolecular nano-fibers and nano-objects. The molecules were for example tailored to function as nucleating/clarifying agents for semi-crystalline polymers, as charge storage additives in electret materials, as nano-fibers for filtration applications and as efficient organo- and hydrogelators.

### **A2: Polymer foams**

*Volker Altstädt, Polymer Engineering*

Due to the unique properties of polymer foams, a large number of innovative applications can be realized. These include packaging with reduced material costs, aerospace and automotive parts with good property-to-weight ratios, decreased thermal conductivity, and enhanced acoustic and mechanical damping.

The first part of the module focuses on the fundamental physics of polymer foams, including a detailed discussion of the foaming processes currently utilized both in academia and in industry as well as the resulting structure-property-relationships. Thereby, different types of polymer foams (particle foams, reactive polyurethane foams (PUR), extruded and injection-molded foams) and their typical properties and applications are introduced. In addition, current scientific approaches towards the control of cell nucleation, cell growth and volume expansion will be presented. Innovations (micro- to nano-cellular) and the hierarchical structuring of polymeric foams are also highlighted. Finally, the students will learn how to obtain tailored foam morphologies – and properties.

This oral part is followed by an experimental session taking place in our laboratories and pilot plant stations. More precisely, a practical introduction into foam injection-molding and foam extrusion is given using commercial machines. Finally, new trends and promising approaches as well as remaining questions will be discussed with the “foaming experts” of Polymer Engineering group.

### **A3: Multifunctional Colloids - From Simple Building Blocks to Modern Devices**

*Prof. Dr. Anna Schenk, Prof. Dr. Markus Retsch, Physical Chemistry Department*

Colloidal particles represent a materials class with a vast range of composition, size, and shape. The unique properties of colloids can mainly be related to their enormous surface to volume ratio and differ significantly from their respective bulk materials. The functionality of such particles can be further enhanced by self-assembly of such building blocks into regular films or arrays, which for instance are known as colloidal crystals.

In this module, we give a detailed introduction into the synthesis, characterization and application of colloidal particles. We will focus on a range of materials such as polymers, metals, and metal oxides, which can also be combined to yield composite materials. Important concepts in colloidal science, in particular the stability of colloidal dispersions and forces influencing colloidal stability, will be introduced. The relevance of these concepts will be discussed in the light of self-assembled materials consisting of colloidal building blocks. Such materials are promising platforms for modern sensors and photovoltaic devices.

### **A4: From Interaction Forces to Nanorobotics**

*Georg Papastavrou, Physical Chemistry II*

Interfacial forces determine many properties like friction, adhesion, or wetting. In recent years, the atomic force microscope (AFM) has developed into a versatile tool for measuring such forces at the nanometer scale with force resolutions in the order of few tenths of a pico-Newton. Such force measurements allow not only to determine the interaction on the level of single polymer chains but as well to explore mechanical properties of nano- and colloidal objects not accessible by other techniques.

In this module, we will demonstrate how the increasing miniaturization of devices becomes on one hand limited by the aforementioned surface forces but on the other hand these allow for radically new types of technology, which until some years ago would be attributed to science fiction. Such fields included micro- and nanorobotics, self-propelling colloids or new types of analytical devices that can flow in blood vessels. The participants will have the possibility to measure and “feel” surface forces, such as the extension of a single polymer chain, aspirate colloidal particles by nanofluidics and to manipulate colloidal objects.

## **B1: Color Formation in Organic Light Emitting Devices (OLEDs) - A Combined Chemistry and Physics Approach**

*Peter Strohmriegel, Macromolecular Chemistry I*

*Anna Köhler, Experimental Physics II*

Colors have attracted people for thousands of years. In the first part of the interdisciplinary course, a short introduction in the basics of color formation and color mixing will be given. Afterwards, the principles of Organic-Light Emitting Devices (OLEDs) will be introduced with special emphasis on the different materials used.

The second part of the course gives an introduction to the photophysics of OLEDs. In such devices the physical principles of energy transfer from a host material to a guest molecule are used to generate different colors in an energy efficient way. The detailed understanding of the photophysics of organic semiconductors has paved the way to the commercialization of full color OLED-displays.

## **B2: Solar Energy Conversion and Energy Storage**

*Sven Hüttner (Juniorprof. Solar Energy) Keylab "Device Engineering"*

The development of alternative ways for energy conversion and energy storage belongs to one of the great challenges we have to face in the 21st century. Solar energy conversion will make a significant contribution within the future mix of energy sources.

In this module we will give detailed presentation of the state of the art and developing solar cell technologies. The presentation is beyond a simple listening of technologies, and fundamental questions in chemistry, physics and material science will be highlighted. This includes general concept of light harvesting – mimicking nature, materials for solar cells (inorganic, organic and hybrid semiconductors), enhancement of light absorption and charge generation, limitations in solar cells as well as fabrication and characterization techniques.

A closely related field is energy storage. The future mobile devices, electro mobility and electric cars as well as the stabilization of our more and more complex growing energy supply grid will require new and sophisticated batteries. Out of the many promising concepts we will give an introduction to Li-Ion batteries and the ongoing research objectives.

This course will provide a substantial overview of current research in solar cells and Li-Ion batteries and demonstrate the ongoing research in the Keylab "Device Engineering" of the University Bayreuth. In a lab course (approx. 3h) we will explain the facilities within the Keylab and demonstrate the processing and characterization of a novel hybrid solar cell.

### **B3: Advanced Laser Techniques: Confocal Raman and Fluorescence Lifetime Imaging (FLIM) Microscopy and Holographic Methods**

*Lothar Kador, BIMF*

Confocal microscopy is a powerful technique for imaging samples in all three dimensions of space. It can be easily combined with the analysis of secondary radiation such as, e.g., Raman scattering or fluorescence light. We will especially discuss the methods of confocal Raman microscopy and confocal fluorescence lifetime imaging (FLIM) microscopy. Whereas the former technique yields spatially resolved information about the chemical composition of the sample, the FLIM method maps the excited-state lifetime of fluorophores. Special emphasis will be laid on FLIM experiments in the frequency domain which use a cw laser amplitude-modulated in the radio-frequency (rf) regime rather than a pulsed laser. In this context, some fundamentals of rf experiments will be touched as well.

In the second part of the lecture, an introduction to holography and some of its possible applications will be given. As an important model system, we will consider the azobenzene molecule and its photophysics. We will address the formation of volume phase gratings and surface relief gratings and discuss the different properties of thin and thick holograms. The project part will be devoted to practical demonstrations of one of these techniques.

### **C1: The fascination of pattern formation and self-organization:**

#### **Basic principles, applications, possible directions**

*Walter Zimmermann, Theoretical Physics I*

Pattern formation and self-organization are fundamental strategies in nature, which fascinate both the layman and researchers from many disciplines. In addition to their aesthetic appeal, the function of the patterns in nature are of central interest.

In this course I will give an introduction to the field and explain some main concepts in the context of experiments. Using several examples from physics, biology, chemistry or material science, I will illustrate that the mechanism driving a spatially extended pattern, like a stripe or traveling wave pattern, are vastly different in diverse systems. Stripe patterns, for instance, are found in biology (skin pattern, segmentation ...), chemistry (Turing, microphases in Blockcopolymers... ), Physics (convection, Taylor-vortices... ), material science (wrinkles ...) and geoscience (atmosphere, continental drift ...). Traveling waves are found in fluids or they occur during cell division of E.coli. Further examples are explained, such as hexagonal patterns (e. g. cloud, perma frost or vegetation patterns), spirals or synchronization phenomena.

I will explain - qualitatively and in terms of basic models – that each nonlinear pattern has a number of robust and system-independent properties and that the concepts of pattern formation provide a framework for their system-independent, generic properties. Why are patterns of different wavenumbers stable in inhomogeneous systems (variability)? By which generic principles can a pattern be selected or controlled? How do patterns interact with their environment such as boundaries or inhomogeneities? Which functions do patterns in nature fulfill? Besides addressing these elementary questions, I will highlight some recent developments and applications as well as possible future direction of pattern formation.

## **C2: Physical Properties of Liquid Crystals: From Low Molecular Weight Materials to Elastomers**

*Helmut R. Brand, Theoretical Physics III*

The field of liquid crystals will be introduced. In one special topic we cover selected LC phases. The second special topic deals with physical properties and methods. In the project afternoon we will discuss selected literature and in particular the derivation of the Frank elastic energy for a nematic liquid crystal.

## **C3: Diffusion and Dynamics in Polymers**

*Werner Köhler, Experimental Physics, Polymer Physics*

Diffusion, the uncorrelated motion of molecules, plays a key role in understanding dynamic processes in macromolecular systems. In the first part of this topic basic concepts of how polymers diffuse in the bulk and in solution are introduced. The difference between self and collective diffusion is discussed and it is shown that a temperature gradient can also induce mass diffusion. Basic models for the description of polymer dynamics are introduced.

Relevant experimental techniques for the measurement of diffusion coefficients are discussed in the second part, and state of the art experiments can be seen in the laboratory.

The lectures will cover phenomenology of diffusion, including polymer models, linear laws, self diffusion, collective and thermal diffusion, and the Rouse and reptation model. As experimental techniques, light scattering and transient holography will be covered.

## **D1: Protein and DNA self-assembled functional nanostructures**

*Thomas Scheibel, Martin Humenik, Melanie Scheibel, Biomaterials*

Novel assembly strategies and types of nanomaterials are required to solve nowadays-technological challenges. Self-assembly processes, which are independent of external energy sources and unlimited in dimensional scaling, became a very promising approach. Self-assembled biopolymers offer several advantages, since evolutionary gained monomer units possess well-tuned functions allowing self-assembled biopolymers with properties featured by chemical and physical addressability, specific recognition, functionality and higher order complexity, all of them defined in distinct monomers sequences.

In this module, we introduce recent developments in self-assembled DNA and protein polymers as well as hybrid entities thereof for constructing of complex hierarchical materials in “bottom up” approaches with nanoscale architecture and programmable functions.

In the practical part of the course, we will demonstrate possible analyses of a working DNAzyme nanomotor and self-assembly of spider silk protein into nanofibrils.

## **D2: Biopolymer-based biofabrication for regenerative tissue engineering**

*Thomas Scheibel, Sahar Salehi, Hendrik Bargel, Biomaterials*

Modern regenerative medicine aims at the functional regeneration of tissues through stimulation and support of the endogenous regeneration potential of the human body. This approach longs for novel materials for bone, ligament and skin substitutes or nerve regeneration characterized by their defined three-dimensional structure, a tissue-related hierarchical morphology, and an adjusted biochemical composition. In order to gain such biomaterials, multidisciplinary approaches combining materials science and processing technologies, natural sciences and medicine are necessary. Biofabrication is an emerging field in the area of biomaterials, aiming at the generation of three-dimensional structures from materials that may contain vital cells and that allow the generation of scaffolds with high survival rates of the embedded cells. Different biopolymers such as gelatin, collagen, silk or alginate are extensively used for biofabricating and they can be processed using different technologies, involving various spinning and coating methods as well as hydrogel formation. The physical and mechanical properties of the materials as well as their morphologies and the cell compatibility can be analyzed to evaluate the suitability for development of 2- and 3-D scaffolds.

The overview of this module is 1) introduction and demonstration of several processing methods of the model biopolymer spider silk protein including electro-spinning, dip-coating etc., and 2) introduction to tissue engineering and specifically skeletal muscle tissue regeneration, as well as demonstration of different types of scaffolds cultured with muscle cells.

## **D3: From molecular detail to genome-wide view**

*Claus D. Kuhn, ENB Junior Research Group "Gene regulation by non-coding RNA", Biopolymere*

Understanding biological processes in molecular detail is a pre-requisite for the development of modern treatments for disease. Since structural biology possesses the tools to reveal biological snapshots at atomic resolution, it is the method of choice to unravel molecular details. However, understanding the molecular details of a single molecular interaction does not allow for conclusions concerning an entire organism. This is why modern drug development has to bridge between understanding the molecular details of a given interaction and its organism-wide implications.

Therefore, the ENB beginner module will cover both aspects, modern techniques to unravel atomic details of biomolecules and their genome-wide impact. Specifically, the module will cover the interaction between nucleic acids and proteins with an emphasis on the interaction between non-coding RNAs and proteins. In two half-day sessions the ENB students will gain insights into the theoretical and practical aspects of studying protein-RNA interactions in molecular detail and in a genome-wide context. In more detail, the module will cover biochemical aspects ranging from the recombinant production of protein complexes to their study using mass spectrometry, X-ray crystallography and cryo-electron microscopy. In addition, the students will be given an introduction to bioinformatics tools with which it is possible to study the impact of non-coding RNA molecules genome-wide.