1.	Field of study	Biophysics
2.	Faculty	Faculty of Science and Technology
3.	Academic year of entry	2022/2023 (winter term), 2023/2024 (winter term), 2024/2025 (winter term)
4.	Level of qualifications/degree	second-cycle studies
5.	Degree profile	general academic
6.	Mode of study	full-time

Module: Polymer Science and Engineering

Module code: W4-2BF-MB-21-05

1. Number of the ECTS credits: 6

2. Learning outcomes of the module

code	description	learning outcomes of the programme	level of competence (scale 1-5)
MB_05_1	the student will be aware of the specific characteristics of the materials included in the class of polymers, particularly with respect to structure and properties	KBF_K01 KBF_W02	3 4
MB_05_2	the student will acquire knowledge of both mechanisms for synthesizing polymeric materials and relevant industrial production and processing technologies	KBF_W02	4
MB_05_3	the student will acquire basic knowledge of the principal experimental techniques for characterizing the physical-chemical properties of polymeric materials	KBF_W04 KBF_W10	4 4

3. Module description

Description	Introduction to the course. Subject, tentative program, goals. Introductory survey on the universe of polymers, classification in plastics and elastomers, recyclable and not recyclable polymers. Historical milestones of polymer science and engineering. Basic review of general concepts in polymer science. Molecular structure, homo- and copolymers, the functionality of a monomer, possible skeletal configurations: linear, branched, and crosslinked polymers. Classification of polymers as thermoplastics, elastomers, and thermosets. Semi-crystalline and amorphous thermoplastics. Melting and glass transition. Survey on the typical values of properties (mechanical, electrical, density, thermal stability) of most employed thermoplastics, thermosets, and elastomers. Deformation mechanisms acting in polymers at the microscopic scale and factors that influence the mechanical response. Viscoelasticity of polymers. Molecular weight, molar masses, and degree of polymerization.

	Generalities of step-growth polymerization. Linear step polycondensation and polyaddition reactions. Control of degree of polymerization in step-growth reactions: Carothers theory and statistical analysis. Kinetics of step polymerization and methods for controlling reactions. Network step polyaddition. Gelation: significance, problems in the quantitative definition of the gel-point, consequences at microscopic and macroscopic scales. Carothers theory and Flory's theory of gelation. Brief mention of dendrimers and hyperbranched polymers. Generalities of chain-growth polymerizations. Stages of a linear chain-growth polyaddition. Production of free radicals activators by thermolysis, photolysis, and redox reactions. Propagation stage. Termination by combination and disproportionation. Termination by intra- and inter-molecular chain transfer. Kinetics of linear chain polyadditions and steady-state conditions. Degree of polymerization. Diffusion constraints and diffusion-controlled reactions. Autoacceleration. Effects of chain transfer. Molar mass distribution. Effects of temperature. Ceiling temperature. Industrial methods for polymerization: bulk, solution, suspension, and emulsion processes. Network radical polymerization by crosslinking monomers. Network radical polymerization of unsaturated (pre-)polymers. Thermodynamics of ideal solutions. Liquid lattice, Gibbs free-energy for mixing, configurational entropy. The Flory-Huggins theory and its limitations. Chemical potential. Dilute polymer solutions. The cohesive density approach for predictions of polymer solubility. Chain dimensions: the freely-jointed chain model, bond angle constraints and short-range steric restrictions, stiffness of a polymer chain. Long-range steric interactions and chains with excluded volume. Expansion parameters for the end-to-end distance and for the gyration radius of a polymer molecule coil. Frictional properties of polymers in solutions. Free-draining and non-draining regimes. Hydrodynamic volume and intrinsic viscosity of a polymer in solution in the non-draining limit: the Flory-Fox and the Mark-Houwink-Sakurada equations. Diffusion process in the non-draining limit. The behavior of polyelectrolytes in solution. Characterization of polymers at a molecular level. Techniques for measuring the number average molar mass based on colligative effects. Membrane osmometry. Vapour pressure osmometry. Ebulliometry and cryoscopy. End-group analysis. Scattering methods for characterization of polymers: static light scattering by liquids and solutions of small molecules and scattering by large molecules in solution. Effect of molar mass dispersity. The Zimm- the plot method for analysis of data. Dynamic light scattering. Photon correlation spectroscopy. Small-angle X-ray and neutron scattering. Purposes, limits, and methods for SAXS and SANS analysis. Measurement of frictional properties of polymers in solutions. Dilute solution viscometry. The intrinsic viscosity, the Huggins equation for the reduced viscosity, and the Kraemer equation for the inherent viscosity. Determination of average molar mass and expansion parameter for polymer molecules in solutions. Use of capillary viscometers for measuring the relative viscosity of a polymer in solution. Differential viscometer. Molar mass distribution. Fractionation of dilute Polymer Solutions by Phase-Separation. Gel permeation chromatography: separation by size exclusion, GPC calibration, and data analysis, universal calibration for GPC. Porous gels and eluants for GPC. Instrumentation and procedures for GPC. Mass spectroscopy (MS). Mass spectra of polymers. ESI and MALDI methods for soft ionization. Time-of-flight (ToF) mass spectroscopy. Analysis of MALDI-TOF mass spectra of polymers. Use of MALDI MS for examining the chemical structure of polymers. Spectroscopic methods for characterization of chemical composition and molecular microstructure of polymers. The principles of spectroscopy and the Lambert-Beer law. Principles of UV-vis spectroscopy, applications in polymer science, essential apparatus, and experimental procedures.

	Principles of IR spectroscopy, applications in polymer science, apparatus and experimental procedures, interpretation of IR spectra. Principles of Raman spectroscopy, applications in polymer science, interpretation of Raman spectra. Brief mention of Raman microscopy. Principles of NMR spectroscopy, interpretation of NMR spectra, absorption splitting by J-coupling. Applications of NMR spectroscopy in polymer science. The amorphous state of polymers. The glass transition and its characteristics. Free volume theories. Factors controlling Tg. Macromolecular dynamics in the amorphous state. The Rouse-Bueche theory. The de Gennes reptation theory. Different paths to a glass transition: cooling, compression, polymerization. The crystalline state in polymers. Evidence and characteristics of polymer crystal structures. Crystals structures for most common polymers. Characteristics of crystals obtained from either dilute solutions, melt cooling, or solid-state polymerization. Polymer single crystals. Lamellae and spherulites. Semi-crystalline polymers and determination of the degree of crystallinity. Crystal thickness. Oriented crystals and polymer fibers. Defects in polymer crystals. Kinetics and thermodynamics of crystallization. Melting of crystalline polymers. Equilibrium melting temperature. Factors that influence melting of polymers. Effects on the melting temperature of crystal thickness, chemical structure, molar mass, branching, copolymerization, annealing. Relationship between Tm and Tg. Differential scanning calorimetry (DSC): traditional power-compensation and heat-flux apparatuses, experimental procedures, and calibration. Qualitative and quantitative interpretation of DSC thermograms. Modulated-temperature DSC (MTDSC), separation of reversing and non-reversing thermal events. Crystal perfection before melting. The elasticity of rubbers. Molecular structural requirements for a polymer to show elastomeric properties. Elastomers as entropic springs. Natural rubber. Vulcanization. Mechanical behavior of elastomers. Thermodynamics of elastomer deformation. The thermoelastic inversion effects. Statistical theory of elastomer deformation. Effects of entanglements, loops, and chain end. Stress-strain behavior of rubbers. Strain-induced crystallization. Electrical properties of polymers. Survey on the variety of possible electrical properties within the class of polymeric materials. A brief review of the classical and the band models for current transport in conductors and semiconductors. Inherently conducting polymers. Conjugated polymers and their molecular structure. The case of polyacetylene: structure, explanation of its conductivity, doping, polarons, and solitons. Ionic conduction in polymers: electrophoresis of ionic species from ionomers or from impurities. Electrical properties of insulating matrix/conducting fillers composites. Percolative behavior of the electrical conductivity. Factors influencing the critical value of the filler volume fraction. Polymers as insulators: the dielectric breakdown phenomenon and the dielectric strength of polymers. Polymer dielectrics: the different mechanisms of electric polarization occurring in polymers, behavior under time-varying electric fields, the complex dielectric permittivity, and the dielectric spectrum. Dielectric relaxation processes and models for their description. Dielectric spectroscopy methods for measuring and analyzing the complex permittivity spectrum. A dielectric spectrum of a glass former: recognizable patterns in the behavior of dielectric constant and loss factor; multiple relaxations, dielectric parameters, ionic conduction. Discussion about the influence of temperature on the spectra and the dielectric parameters of a supercooled glass former. Evolution of the dielectric spectra and of the dielectric parameters in time-varying systems: the case of polymerization reactions. Dielectric analysis of chemically, thermally and mechanically induced glass transition: differences, analogies, and attempts for a unified description of the glass transition. Microwave heating.

	Processing of polymers. Principles of the techniques for the processing of polymers. low properties of polymer melts: bulk deformation, elongational flow (tension stiffening and tension thinning), shear flow (shear thinning). Melt flow index. Apparent viscosity as a function of temperature and molar mass. Viscoelasticity of molten polymers and swell ratio. Cooling and solidification of polymer melts. Extrusion. Injection moulding. Thermoforming. Blow moulding. Compression moulding. Transfer moulding.
Prerequisites	

4. Assessment of the learning outcomes of the module

code	type	description	learning outcomes of the module
MB_05_w_1	exam	The final exam is composed of a final oral examination which has a duration averaging between 40 and 60 minutes. During the oral exam, the student can be also required to solve open questions/exercises/problems. The student will be assessed on his/her demonstrated ability to discuss the course contents with critical awareness and with the property of an expression by starting from problems/exercises/questions proposed by the exam commission. The oral test is not passed if the candidate demonstrates to not be able to express him/herself in a clean and proper language and if the candidate does not correctly answer at least those questions concerning the very basic parts of the course. Knowledge of the micro-mechanics of deformation of metals, ceramics, polymers, and composites. Knowledge of the fundamentals of elasticity and viscoelasticity, plasticity, imperfections/defects in crystals, deformation and strain-hardening, fracture, strengthening of alloys, martensitic transformations	MB_05_1, MB_05_2, MB_05_3

5. Forms of teaching

code	form of teaching			required hours of student's own work		assessment of the learning outcomes of the module
	type	description (including teaching methods)	number of hours	description	number of hours	
MB_05_fs_1	lecture	Detailed discussion by the lecturer of the issues listed in the table "module description" using the table and/or multimedia presentations	48	Supplementary reading, working with the textbook	102	MB_05_w_1