

The course is organized in seven sections:

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| <b>A</b> | Definition of soft matter, self-assembly and the key interaction mechanisms: van der Waals attraction, steric repulsion, hydrogen bonding and the hydrophobic effect. |
| <b>B</b> | Colloids and their stabilization; gels and glasses  |
| <b>C</b> | Liquid crystals, lyotropic and thermotropic, low molar mass and polymeric.  |
| <b>D</b> | Self-assembly in polymeric soft matter.   |
| <b>E</b> | Key characterization techniques in soft matter physics  |
| <b>F</b> | Biological soft matter  |

For each section we have defined the following primary learning objectives:

| Section  | After this section you will (among other things) be able to:  |
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| <b>A</b> | <ul style="list-style-type: none"> <li>• define the term 'soft matter', give some examples and list characteristic features common to all soft matter;</li> <li>• explain what is meant with 'self-assembly' and distinguish between static and dynamic self-assembly, providing a definition of each subclass;</li> <li>• list key interactions in soft matter, categorize them according to whether they are primarily enthalpic or entropic in nature, and give orders of magnitude for the energies of the most important interactions;</li> <li>• explain the concept Van der Waals interaction and distinguish the three subcategories;</li> <li>• account for Hamaker's approximative approach to quantify London interactions;</li> <li>• tell whether a molecule or molecule fragment is a good partner in hydrogen bonding, distinguish between hydrogen bond donors and acceptors, give a qualitative definition of hydrogen bonding, give representative examples of prominent hydrogen bonding molecules and account for the effects of hydrogen bonding on their physical properties;</li> <li>• explain the concept "hydrophobic effect" as well as its origin and name some of its important consequences;</li> <li>• explain the concept 'aromatic interactions' and give examples of molecules where such are important.</li> </ul> |

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| <b>B</b> | <ul style="list-style-type: none"> <li>• define the concept 'electric double layer', account for the three main models for describing it, and give an elementary explanation of how it arises;</li> <li>• define the concepts 'surface tension' and 'interfacial tension' and explain their origins;</li> <li>• define the term 'Laplace pressure' (also called 'capillary pressure'), explain its origin, and discuss its consequences in case of curved interfaces, including the phenomenon Ostwald ripening;</li> <li>• define the concepts 'solvation sheath' and 'hydrodynamic radius' and account for how the latter can be measured experimentally;</li> <li>• define the concept 'zeta potential', account for how it can be measured experimentally, and discuss its importance for colloidal stability and how it may relate to pH;</li> <li>• derive the most simplest (linearized) form of the Poisson-Boltzmann equation, discuss its consequences and define the Debye screening length;</li> <li>• define the concept 'ionic strength' and discuss its role in determining colloidal stability and effective particle size;</li> <li>• give a qualitative account for the key concepts of DLVO theory;</li> <li>• use the Reynolds number to provide a comparison between viscous and inertial forces, and account for the unusual phenomena occurring at low Reynolds number;</li> <li>• define the concept 'non-Newtonian fluid' and give some examples;</li> <li>• define the terms 'colloid', 'disperse phase', 'continuous phase', 'dispersion', 'suspension', 'emulsion', 'foam', 'lyophobic', 'lyophilic', 'sol' and give some prominent examples;</li> <li>• describe the two main routes for lyophobic colloid preparation, starting from dry powders of the phase to be dispersed or from a molecularly dispersed solution;</li> <li>• discuss the role of Brownian motion in colloids, in terms of stabilizing as well as destabilizing suspensions, and give a qualitative account for how particle size influences the stability of a colloid of uncoated particles;</li> <li>• give examples of methods for stabilizing colloidal suspensions and discuss advantages and drawbacks of each;</li> <li>• explain the concepts 'polymer bridging' and 'depletion attraction' and discuss how they can be used to destabilize colloids;</li> <li>• account for the effects of sedimentation and centrifugation on colloidal suspensions;</li> <li>• define the terms 'amphiphile' and 'surfactant', draw typical examples, and account for their role in stabilizing colloids and their behavior in water as a function of concentration;</li> <li>• define the terms 'micelle', Krafft temperature and 'critical micelle concentration' and account for how the latter can be measured experimentally;</li> <li>• discuss how colloids may crystallize and how the interactions between particles influence the nature of the aggregates;</li> <li>• discuss how different continuous phases can provide different interactions, and how the tailoring of the particle interface for each continuous phase can give directed interactions;</li> <li>• define the concepts 'glass' and 'glass transition' and contrast them to the concepts 'gel' and 'gelation';</li> <li>• describe the sol-gel transition and distinguish between physical and chemical gels;</li> <li>• define the concept 'percolation' and give some examples of percolation phenomena and their consequences for the macroscopic properties of a colloid;</li> <li>• describe the structures that can be formed by evaporation-induced self-assembly and explain the Marangoni and coffee ring effects;</li> </ul> |

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| C       | <ul style="list-style-type: none"> <li>• define the term 'liquid crystal' and distinguish between the thermotropic and lyotropic classes, as well as between the main phases (nematic, smectic, cholesteric, columnar, ...);</li> <li>• list prerequisites on molecules and/or particles in order that they can form a liquid crystal phase, in each case specifying which liquid crystal class can be expected;</li> <li>• define the concepts of long-range 'orientational order' and 'positional order';</li> <li>• define the director concept;</li> <li>• write down the scalar orientational order parameter, discuss its meaning and its limiting values, and draw its typical temperature dependence for a thermotropic material;</li> <li>• define the 'packing parameter' of amphiphiles and discuss how it is influenced by the design of the molecule as well as by the concentration;</li> <li>• identify appropriate values of packing parameters for obtaining isotropic micellar phases, nematic phases and lamellar phases, respectively, in aqueous surfactant solutions;</li> <li>• explain the typical lyotropic liquid crystal phase diagrams of ionic surfactants in water as a function of concentration;</li> <li>• define the concepts 'Langmuir film' and 'Langmuir-Blodgett films', explain their respective origins and describe how they are made experimentally;</li> <li>• describe the design and function of a Langmuir trough and account for the 2D phase diagram of a Langmuir film as a function of surface pressure;</li> <li>• define the concept 'self-assembled monolayer' (SAM) and give examples of combinations of molecules and substrates suitable for making SAMs;</li> <li>• define the concept of a 'phase' and explain how two isotropic liquid phases may coexist;</li> <li>• formulate Gibbs' phase rule and apply it to phase coexistence situations for various systems;</li> <li>• establish (experimentally) the phase diagram of a mixture of two thermotropic liquid crystals as a function of temperature and composition;</li> <li>• describe the full process of a first-order phase transition in a mixture;</li> <li>• define the concepts 'critical solution temperature' and 'azeotrope';</li> <li>• correctly interpret binary and ternary phase diagrams, apply the lever rule to establish the relative quantities of phases in coexistence, and explain the terms 'eutectic' and 'peritectic';</li> <li>• define the concept of a symmetry operation and define the symmetry classes of isotropic, nematic, smectic-A and smectic-C phases, as well as their respective chiral versions;</li> <li>• define the concept 'chirality' and discuss its consequences for liquid crystals;</li> <li>• define the concept 'liquid crystal elastomer' and describe and explain their remarkable mechanical properties, in particular their ability to change shape at phase transitions;</li> <li>• define the concept 'random coil' polymer conformation and describe the relation between polymer conformation and elasticity of rubbers;</li> <li>• explain why liquid crystalline polymers are useful for strong fiber materials;</li> <li>• define and name the three fundamental liquid crystal deformations and write the expression for their respective contributions to the elastic free energy;</li> <li>• describe the twisted nematic liquid crystal display and explain its optics;</li> <li>• account for how a nematic response to an applied electric field and, based on this, explain how a twisted nematic display is switched between dark and bright;</li> <li>• define the 'Frederiks transition' and the 'Frederiks threshold';</li> <li>• discuss how different liquid crystal parameters influence the switching speed of a liquid crystal display;</li> <li>• qualitatively account for the function of VA and IPS liquid crystal displays;</li> <li>• explain how the alignment of a liquid crystal can be controlled experimentally;</li> <li>• define the three Miesowicz viscosities, as well as the rotational viscosities in liquid crystals, and explain how each can be measured experimentally;</li> <li>• provide a simple symmetry argument for why a chiral smectic-C (SmC*) phase exhibits a spontaneous polarization, and describe how such a phase can be made to exhibit ferroelectric switching;</li> </ul> |

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| <b>C</b> | <ul style="list-style-type: none"> <li>• describe the optical properties of cholesteric liquid crystals as a function of their pitch length, including the definition and explanation of the concept 'selective reflection';</li> <li>• define the concepts 'topological defect', 'dislocation' and 'disclination' and give examples of each in liquid crystals;</li> <li>• quantify and attribute signs to any type of disclination, and identify those disclinations that are allowed in a phase with a particular given symmetry;</li> <li>• account for the Volterra process and how it can be used to quantify disclinations;</li> <li>• discuss the relation between topological defects and surface curvature.</li> </ul>  |
| <b>D</b> | <ul style="list-style-type: none"> <li>• define the concept 'block copolymer';</li> <li>• design a block copolymer such that it may display interesting self-assembly phenomena;</li> <li>• account for which structures may form from a block copolymer drying from solution, and correlate these structures to the composition fraction (and define the composition fraction);</li> <li>• discuss self-assembly of amphiphilic block copolymers in water.</li> </ul>  |
| <b>E</b> | <ul style="list-style-type: none"> <li>• explain the concept 'birefringence' and its effect on the polarization state of light entering a birefringent medium, as a function of sample thickness and the orientation of the optic axis;</li> <li>• correlate the magnitude of birefringence with the degree of orientational order in liquid crystals as well as with the polarizability anisotropy of the molecules forming the phase;</li> <li>• define the optical indicatrix and relate it to the dielectric indicatrix;</li> <li>• define the concept 'optic axis' and draw it for discotic and for rod-shaped liquid crystals;</li> <li>• account for the effects of <math>\lambda/4</math> and <math>\lambda/2</math> plates;</li> <li>• use a polarizing optical microscope and account for the function of its main components;</li> <li>• discuss the benefits and limitations of dark field, confocal and fluorescence microscopy techniques, as well as account for their requirements;</li> <li>• describe in qualitative terms the Pockels and Kerr effects;</li> <li>• describe and explain the most typical polarizing microscopy textures of liquid crystals, e.g. schlieren and fingerprint textures;</li> <li>• utilize a Michel-Levy diagram to correlate birefringence, sample thickness and sample color between crossed polarizers;</li> </ul> |



| Section  | After this section you will (among other things) be able to:   |
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| <b>F</b> | <ul style="list-style-type: none"> <li>• give a greatly simplified description of the external and internal structure of a eukaryotic cell and identify where liquid crystalline membranes are found in the cell;</li> <li>• list the three most common components of a biomembrane and discuss how membrane curvature is linked to local membrane composition;</li> <li>• define the concept 'vesicle' and compare it with micelles and with lamellar lyotropic liquid crystal phases;</li> <li>• define the concepts 'nucleic acid', 'nucleotide', 'nucleoside' and 'nucleobase';</li> <li>• define and explain nucleic acid complementarity;</li> <li>• describe the structure of complementary and non-complementary DNA strands in aqueous solution as a function of temperature;</li> <li>• explain Ned Seeman's concept for artificial DNA-based nanotechnology and give examples of structures that can be formed;</li> <li>• explain DNA origami and give examples of structures that can be formed;</li> <li>• explain how DNA hybrids can be used to control colloid crystallization;</li> <li>• define the concepts 'protein', 'amino acid' and 'peptide bond';</li> <li>• discuss the four structural levels of protein organization and define the key concepts, such as alpha helix and beta strands/sheets/barrels;</li> <li>• describe the composition of a virus and some typical shapes;</li> <li>• explain how certain types of virus can be used for self-assembly experiments in soft matter physics (which viruses would you choose and why?).</li> </ul> |