ENVIRONMENTAL AND BIOMATERIAL SCIENCES			
A. Povinné kurzy (Compulsory courses)	**B. Povinně volitelné teoretické kurzy (Compulsory optional courses)**	**C. Povinně volitelné praktické kurzy (Specialized laboratories and practicals)**	**D. Povinně volitelné doplňkové kurzy (Optional courses)**
Conference participation	Advances in biotechnology	Laboratory I – Cleanroom	Climate change: Influencing factors and impacts on ecosystem services
Doctoral seminar I, II, and III	Advanced biophysical methods in nanomaterial research	Laboratory II – Circular chemistry	High-energy X-ray (synchrotron-based X-ray) analyses
International internship	Advances in the application of analytical techniques	Laboratory III – ISO certified analytical measurements	Life-cycle assessment – Sustainable and eco-informed selection of materials
Publication and dissemination	Advances in the characterization techniques of materials	Laboratory IV – Advanced microscopy of materials	Mitigation of pollution and toxicity in the environment
Thesis preparation I, II, III, and IV	Chemistry and physics of surfaces and interfaces	Laboratory V – Synthesis of emerging inorganic materials	Molecular and cell biology for material research
Workshop/summer school	Hydrodynamics	Laboratory VI – Synthesis of emerging organic materials	Principles of circular economy
	Ion-beam synthesis and radiation testing of materials for energetic applications	Laboratory VII – Biomedical and immunology testing	Professional and academic German for scientists
	Luminescence: From molecules to nanoparticles	Laboratory VIII – Application-oriented testing of materials	
	Magnetic properties of functional materials	Laboratory IX – Computational modelling of particle materials and fluid dynamics	
	Materials and living systems		
	Materials and principles of energy storage and conversion		
	Materials for tissue engineering and medical use		
	Materials modelling		
	Materials under extreme conditions		
	Microbiology in material research		
	Porous materials		
	Powders and granular materials		

B. POVINNĚ VOLITELNÉ TEORETICKÉ KURZY (COMPULSORY OPTIONAL COURSES)

B-III – Course details

Course title	**Advances in biotechnology**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	26L	**Hours**	26	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**Dr. rer. nat. Jörg Opitz**				
Lecture(s)	Dr. rer. nat. Jörg Opitz				
Syllabus					

This course focuses on the application of biomimetic principles to the synthesis of nanostructures and nanopatterns primarily on surfaces. The course is based on illustrating genomic and proteomic processes and structures in nature, such as DNA structure and enzyme activities, motor protein structures such as kinesin and how molecular motors work, the structure of parts of the cytoskeleton such as microtubules and their formation, and protein structures on bacteria such as S-layers. The course provides a basic understanding of the underlying biology. The biological knowledge will be applied to engineering tasks such as the formation of a type of molecular electronic structure on surfaces, regular nanoparticle patterns and nanostructures on surfaces, functionalization and modification of biosensor surfaces, and the creation and use of nanomotors for transport on surfaces. The course will also provide the fundamental knowledge to characterize and measure these processes and structures. Students will understand the underlying biological principles and learn to apply them in solving engineering problems. They will have a good insight into recent developments in the field of biomimetics and the subsequent fabrication of nanostructures and patterns for applied engineering tasks. They will be able to critically evaluate current research and literature in the field and contribute to the use of bionanotechnology in their own research.

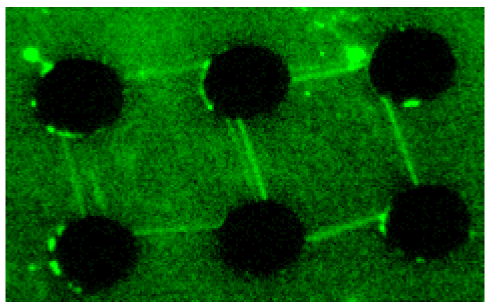

Fig. 1. Stretched DNA is forming a DNA network between gold contact structures.

The main topics of the course are:

1. Cellular machines (structures, functioning in cells and in-vitro assembly).
2. Microtubules (structure, in-vitro growth).
3. Construction and use of microtubules and kinesin motors for surface transport.
4. DNA (structure, enzymes, PCR).
5. DNA-based nanotechnology (DNA origami, DNA aptamers, DNA modification and functionalization).
6. BioNEMS and BioMEMS.
7. Interaction of biomolecules and solid surfaces (chemical and biological surface modification and functionalization).
8. Biotemplating: synthesis of nanomaterials based on proteins (S-layers, microtubule) and DNA, metallization.
9. Antibodies and aptamers - smart nanodevices for biosensors.
10. Underlying physical principles.
11. Characterization and measurement techniques for biomimetic nanomaterials.
12. Biomolecular sensing, sensor principles, and sensor engineering and development.

Literature	

1. L. Fruk, A. Kerbs, *Bionanotechnology - Concepts and Applications*, Cambridge University Press, (2021).
2. J. Chen, Y. Feng, S. MacKay, *Bionanotechnology: Engineering Concepts and Applications*, 1^{st} Ed., McGraw-Hill, (2022).
3. K. Urmann, J. G. Walter, *Aptamers in Biotechnology,* Springer Cham, (2020).
4. Y. Song, D. Cheng, L. Zhao, *Microfluidics: Fundamental, Devices and Applications: Fundamentals and Applications*, Wiley-VCH Verlag, (2018).
5. M. Sheetz, H. Yu, *The Cell as a Machine (Cambridge Texts in Biomedical Engineering)*, Cambridge University Press, (2018).

<table>
<tr><td colspan="7">B-III – Course details</td></tr>
<tr><td>Course title</td><td colspan="6">Advanced biophysical methods in nanomaterial research</td></tr>
<tr><td>Type</td><td colspan="3">B. Povinně volitelné teoretické kurzy (Compulsory optional courses)</td><td colspan="2">Recommended year</td><td>1-2</td></tr>
<tr><td>Course length</td><td>16L + 14l</td><td>Hours</td><td>30</td><td>Credits</td><td colspan="2">20</td></tr>
<tr><td>Course completion</td><td colspan="3">Pre-exam credit, exam</td><td>Teaching type</td><td colspan="2">Lectures, laboratory</td></tr>
<tr><td>Verification</td><td colspan="6">Pre-exam credit: laboratory protocols
Written exam</td></tr>
<tr><td>Guarantor</td><td colspan="6">MSc. Dominika Wrobel, Ph.D.</td></tr>
<tr><td>Lecture(s)</td><td colspan="6">MSc. Dominika Wrobel, Ph.D.
Mgr. Jan Malý, Ph.D.
doc. Ing. Josef Trögl, Ph.D.</td></tr>
<tr><td>Syllabus</td><td colspan="6"></td></tr>
</table>

The course objective is to comprehensively understand the influence of nanomaterials on biological systems such as lipid membranes and proteins, employing both theoretical analysis and empirical exploration. This insight is pivotal for advancing applications in medicine, drug delivery, diagnostics, and other pertinent domains, necessitating an in-depth study of nanoparticle behaviour at molecular and cellular tiers. Moreover, the profound comprehension of nanoparticle architecture and its ensuing implications holds promise for the innovation of more efficient biological systems. Throughout the course, students will also gain practical experience in utilizing cutting-edge laboratory tools for characterizing nanomaterials in biological contexts, thereby equipping them with valuable skills for future research and applications.

This course combines theoretical learning with hands-on training. The main goal is to promote and enhance students' competence in using advanced biophysical and biochemical techniques efficiently. Students will achieve the following skills:

Biophysical nanomaterials characterization: Students will obtain knowledge about the construction of scientific investigation of new nanomaterials as well as biophysical methods used in this area.

Interactions with biological structures: Students will obtain knowledge about the preparation of lipid bilayer model systems and their usage in lipid membranes behaviour investigation, they will also research the influence on proteins of nanoparticles.

Analytical Proficiency: Students will develop a strong foundation in analytical techniques, allowing them to accurately assess and interpret complex biophysical and biochemical data. This skill is essential for making informed scientific conclusions based on experimental results.

Interdisciplinary Integration: The course will emphasize the integration of principles from biology, physics, chemistry, and other related fields. Students will learn how to synthesize knowledge from various disciplines to gain a holistic understanding of complex biological phenomena.

Problem-Solving Skills: Biological systems can present intricate challenges. Through the course, students will develop problem-solving skills to address research questions, troubleshoot experimental issues, and adapt methodologies as needed.

Students will acquire comprehensive insights into the operational principles and application methodologies of cutting-edge analytical instruments. These instruments encompass a spectrofluorimeter, circular dichroism spectrometer, nanosizer, micro-isothermal titration calorimeter (micro-ITC), micro-differential scanning calorimeter (micro-DSC), and the sophisticated nanoparticle tracking analyzer (NTA). Moreover, students will undergo rigorous training in the utilization of specialized software tools for the meticulous analysis of acquired data. Notably, proficiency in the employment of GraphPad Prism7 for data interpretation and statistical analysis will be cultivated. Furthermore, the course will impart advanced knowledge and practical skills pertinent to the construction and execution of intricate analyses concerning novel nanoparticles. Students will become adept at delineating the multifaceted characteristics of these nanoparticles, thereby nurturing their capacity for innovative scientific inquiry within this burgeoning field.

Theoretical part of the course

1. Mechanisms of biological entities interaction with nanomaterials
The interaction of nanomaterials with biological models will be discussed and defined in this section. The biocompatibility issues that might arise as a result of various sorts of interactions.
Sub-sections are:

- nanoparticle surface functionalization by proteins,
- nanoparticle interaction with proteins in biological fluids,
- the influence of protein corona formation on biocompatibility,
- nanoparticle interaction with lipid bilayer,
- the effect of nanoparticle-lipid interaction on membrane structure and function.

2. Biophysical and biochemical concepts
The biophysical and biochemical ideas of nanomaterial construction will be presented in this part in order to achieve the best biofunctionalization of nanomaterials.
Sub-sections are:

- synthesis of functional nanoparticles - functional drug transporters, optimal body circulation, drug release,
- strategies of surface modification of nanoparticles - targeting therapies, decreasing of nanoparticle toxicity and body retention, avoiding protein corona formation.

3. Principles of selected biophysical methods
The most popular biophysical approaches used in nanoparticle characterisation will be given in this section. Biophysical approaches for nanomaterial interaction with biological structures will also be investigated.
Sub-sections are:

- fluorescence techniques,
- calorimetric methods - ITC and DSC,
- light scattering based methods - DLS and NTA,
- circular dichroism – CD.

Practical part of the course
Preparation and characterization of lipid-bilayer and proteins models.
Investigation of nanoparticles interaction with lipid-bilayer and proteins models by several biophysical methods.

Literature

1. A. B. Rubin, *Fundamentals of Biophysics*, 1st Ed., Wiley, (2014).
2. E. J. Chung, L. Leon, C. Rinaldi, *Nanoparticles for Biomedical Applications - Fundamental Concepts, Biological Interactions and Clinical Applications*, Elsevier, (2019).
3. M. A. Williams, *Toxicology of Nanoparticles and Nanomaterials in Human, Terrestrial and Aquatic Systems*, Wiley, (2022).
4. D. E. Vance and J. E. Vance, *Biochemistry of Lipids, Lipoproteins and membranes*, 5th Ed., Elsevier, (2008).
6. J. R. Lakowicz, *Principles of Fluorescence Spectroscopy*, 3rd Ed., Springer, (2006).
7. A. Sze *et al.*, Zeta-potential measurement using the Smoluchowski equation and the slope of the current–time relationship in electroosmotic flow. *J. Col. Sci. Inter.* **260** (2003) 402.

B-III – Course details

Course title	**Advances in the application of analytical techniques**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	20L	**Hours**	20	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**doc. Dr. Ing. Pavel Kuráň**				
Lecture(s)	doc. Dr. Ing. Pavel Kuráň Mgr. Jakub Ederer, Ph.D. Ing. Lucie Oravová, Ph.D. Ing. Ivana Barchánková, Ph.D. prof. Ing. Pavel Janoš, CSc.				

Syllabus

The lectures deepen students' knowledge in the field of modern and advanced analytical methods and their applications in environmental and biomaterial sciences. The course will be dedicated to a survey of trends in new analytical methods with a special focus on the analysis of environmental samples and biomaterial characterization. The aim is to provide a comprehensive overview of advances in the application of analytical methods in environmental analysis, characterization of materials for environmental and biological purposes by taking into account the concept of sustainable analytical chemistry.

The course will be complemented by the "*Laboratory II – Circular economy*" in module C – Specialized laboratories and practicals.

The course consists of the following parts:

1. Trends in analytical methods for environmental organic analysis – water, soil and air pollution, analysis, description and environmental impact of main organic pollutants (microplastics, persistent organic pollutants, industrial dyes…).
2. Advanced separation techniques and applications in the environment – modern trends in sampling and sample preparation techniques.
3. Trends in analytical methods for environmental inorganic analysis – analysis, description and environmental impact of main inorganic pollutants (nanomaterials, heavy metals, radioactive elements…).
4. Multidimensional techniques – trends and applications in environmental and biomaterial sciences.
5. Analytical methods for the characterization of materials for environmental purposes – sorbents, sensors...
6. Mobile analytical methods – application in environmental and biomaterial analysis, merits and disadvantages of their use.
7. Advanced analytical methods in biomaterial science – characterization of biomaterials and modern trends.
8. Electroanalytical methods in environmental and biomaterials analysis – modern trends and emerging applications.
9. Future of environmental analysis and sustainable analytical chemistry.

Literature

1. M. Mitra, P. Patnaik, B. B. Kebbekus, *Environmental Chemical Analysis*, CRC Press, (2018).
2. C. M. Hussain, R. Keçili, *Modern Environmental Analysis Techniques for Pollutants*, Elsevier, (2020).
3. S. Knoll, T. Rösch, C. Huhn, Trends in sample preparation and separation methods for the analysis of very polar and ionic compounds in environmental water and biota samples. *Anal. Bioanal. Chem.* **412** (2020):6149.
4. A.P.R. Santana *et al.*, (Re) thinking towards a sustainable analytical chemistry: Part I: Inorganic elemental sample treatment, and Part II: Alternative solvents and extraction techniques. *TrAC, Trends Anal. Chem.* **152** (2022) 116596.
5. M. Omidi *et al.*, Characterization of biomaterials, in *Biomaterials for Oral and Dental Tissue Engineering*, Woodland Publishing, (2017), Ch. 7.
6. M. Jajje, W. Hammond, P. Tolias, T. Arinzeh, *Characterization of Biomaterials*, Woodhead Publishing, (2016).
7. Ž. Mitić *et al.*, Instrumental methods and techniques for structural and physicochemical characterization of biomaterials and bone tissue: A review. *Mater. Sci. Eng. C* **79** (2017) 930.
8. T. Acter *et al.*, Environmental petroleomics – Application of ultrahigh-resolution mass spectrometry for molecular-level understanding of the fate of spilled oils. *Trends Anal. Chem.* **40** (2023) e00212.

9. C. Liu *et al.*, State of the art overview wearable biohazard gas sensors based on nanosheets for environment monitoring applications. *Trends Anal. Chem.* **40** (2023) e00215.
10. R. Keçili *et al.*, Fluorescent nanosensors based on green carbon dots (CDs) and molecularly imprinted polymers (MIPs) for environmental pollutants. Emerging trends and future prospects. *Trends Anal. Chem.* **40** (2023) e00213.
11. A. Bandyopadhyay, S. Bose, *Characterization of Biomaterials*, Elsevier, (2013).

B-III – Course details

Course title	**Advances in the characterization techniques of materials**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	26L	**Hours**	26	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**doc. Ing. Jiří Orava, Ph.D.**				
Lecture(s)	doc. Ing. Jiří Orava, Ph.D. prof. Spyros N. Yannopoulos doc. Ing. Martin Kormunda, Ph.D. doc. RNDr. Stanislav Daniš, Ph.D. Mgr. Jakub Ederer, Ph.D. Ing. Jiří Henych, Ph.D. Dr. Ing. Birgit Jost Ing. Kamil Lang, CSc., DSc.				
Syllabus					

The course will provide students with detailed knowledge of modern and advanced materials' characterization methods and their applications in environmental, biomaterial and other relevant sciences and technologies. The focus of the course will be to understand the modern trends such as i) complementary types of characterization techniques of materials, represented by Raman and infrared spectroscopy; ii) correlative types of characterization methods, such as transmission electron microscopy (TEM), local-electrode atom-probe tomography combined (LEAPT) with atomic-force microscopy, AFM, (the latter two are shown as an Oralple in Figure 1); and iii) multi-technique characterization for a comprehensive understanding of functional materials (such as monitoring thin-film properties *in-situ* during deposition). In collaboration with the partner institute Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), Dresden, the lectures will also highlight the importance of non-destructive (tomography) and application-oriented characterization methods that can be used to understand the relationship between the atomic structure and macroscopic properties for fast materials screening in biomaterial, environmental, and related, sciences. Such materials analysis is crucial, especially in the fast exploitation of materials and their *in-operando* optimization in biomedical, nanomaterials, and environmental applications, and it is a prerequisite for ensuring fast and reliable commercialization.

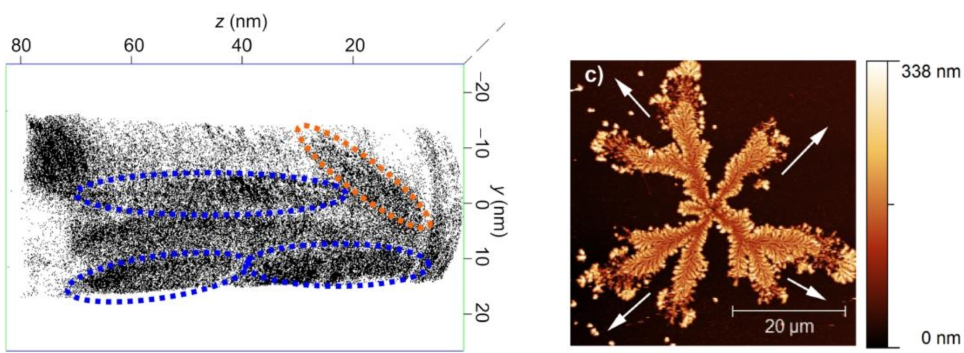

Fig. 1. An Oralple of advanced characterization of materials properties in low-energy and fast-switching new emerging nano-ionic memory based on fast ionic conduction of Ag^+ ions in solid-state amorphous electrolyte (The results are relevant for the theoretical course on "*Materials and principles of energy storage and conversion*". Complementary imaging of preferable migration pathways in *left-panel*: vertical geometry of the memory compositional regions (Ag-rich

and Ag-poor) visualized by local-electrode atom-probe tomography on nanometer length-scale, and *right-panel*: conductive filament formation in lateral geometry imaged by tunnelling atomic-force microscopy. (Figures are from own work).

The course will be flexible and specifically designed to meet the individual needs of each student. The aim will be to provide a theoretical background to a portfolio of techniques which are the most suitable for the topic of the dissertation thesis. The course content will also be moulded to be very complementary to the topics covered by the course "*Advances in the application of analytical techniques*" as both types of analyses can often be done parallel to each other to obtain the most comprehensive information about materials.

The knowledge gained in this theoretical course can be practically applied in the module C – Specialized laboratories and practicals, especially in the practical "*Laboratory I – Cleanroom*", "*Laboratory IV – Advanced microscopy of materials*", and "*Laboratory VIII – Application-oriented characterization of materials*" (the latter will be carried out in the laboratories in IKTS).

A detailed Oralple of some topics which can be covered by the course is shown below (of which some will be selected by the student based on the topic of the dissertation thesis). The list is not full and more specialized techniques may also be covered to suit students' scientific needs. The lectures will highlight issues connected with materials characterization relevant to the doctoral programme.

1. *Modern Raman spectroscopy* – (off)resonance scattering, surface-enhanced Raman scattering, surface-enhanced resonance Raman scattering, more advanced scattering techniques, for Oralple, tip-enhanced Raman scattering relevant for the topic covering atomic-force microscopy, Raman optical activity and UV Raman scattering.
2. *Modern applications of infrared spectroscopy* – the focus will be on covering *in-situ* measuring methods and data interpretation, for Oralple, relevant to powders being used in environmental applications. Principles and issues of studying kinetics of powders formation and pollutants removal at higher temperatures, higher pressures and in reaction atmosphere will be covered. (Non)-invasive spectroscopy.
3. *Atomic-force microscopy (AFM)* – topics of topography imaging modes, tapping, contact, non-contact, torsional resonance modes in AFM will be covered. Imaging in air and different media will be covered. Theoretically, the secondary AFM modes will be explained. Those include lateral force microscopy, phase imaging, magnetic force microscopy, conductive and tunnelling AFM, electric force microscopy, surface potential imaging, adhesion forces imaging, nanomechanical mapping, scanning capacitance microscopy, scanning spreading resistance microscopy, thermal scanning AFM, atomic force acoustic microscopy etc. The lecture will also cover relevant non-imaging modes such as different spectroscopy, force spectroscopy, surface modification techniques, nanolithography, nanoindentation, nanomanipulation etc. The focus will be on highlighting specific issues connected with environmental, nano- and biomaterial, and living-cell samples.
4. *Transmission- (TEM) and scanning-(SEM)-electron microscopy, focused-ion beam milling (FIB)* – (in)elastic scattering, diffraction, instrumentation, and specifics of FIB specimen preparation with a focus on environmental and biological samples. Therefore, covering cryo-techniques of sample preparation, and cryo-imaging. Different diffraction modes including Kikuchi diffraction and CBED mapping. Application of different X-ray spectroscopies, qualitative and quantitative X-ray analysis. Imaging by electron energy-loss spectrometry and EBSD mapping; *in-situ* mechanical testing in e-beam and modern trends in e-beam tomography.
5. *Modern trends in the materials surface-characterization by X-ray photoelectron spectroscopy (XPS)* – the lectures will cover recent and emerging trends in the application of XPS technique in environmental, semiconducting, biomaterial and relevant materials/sciences such as phase identification from valance band analysis; determination of the composition on the nanometre length-scale; probing contaminant effects on properties of materials; mining; metallurgy, organic materials etc. The specific issues connected with each type of material will be discussed and relevant Oralples will be shown.
6. *X-ray diffraction analysis and tomography* – micro-focused diffraction, thermal-dependent diffraction, single-crystal XRD, analysis of complex matrices and thin films. Analysis of film thickness and its non-uniformity, analysing residual stresses and strains in materials. Different length-scale 3-D imaging of materials (X-ray tomography), etc.

Other relevant characterization techniques, modern trends, problems and approaches may include:

7. *Ex-situ* and *in-situ* different length-scale analysis of mechanical properties (for Oralple, nanoindentation) of materials.

8. *Optical properties* – spectroscopic ellipsometry of complex samples, *in-situ* optical (such as fibre-based sensing) monitoring of materials, for Oralple, electrochemical changes in Lithium-ion batteries; principles of biological sensing in the mid-infrared region; photoluminescence measurements…
9. *Local-electrode atom-probe tomography* – theory of nanometre length-scale compositional analysis of materials, different aspects of analysing crystalline vs amorphous materials.
10. *Ultra-fast (flash) calorimetry and heating methods* – modern trends in ultrafast heating calorimetry with heating rates exceeding 10^6 K/s; principles in studying the ultrafast heat-capacity response of different materials (including, for Oralple, exploiting flash annealing in the recycling of (e-)waste to produce graphene and graphene-like products).
11. *Light scattering in soft matter* – static and dynamic light scattering; particle size determination in dispersions, etc.

Literature

1. D. N. G. Krishna, J. Philip, Review on surface-characterization applications of X-ray photoelectron spectroscopy (XPS): Recent developments and challenges. *Appl. Surf. Sci. Adv.* **12** (2022) 100332.
2. R. F. Ziesche *et al.*, Multi-dimensional characterization of battery materials. *Adv. Ener. Mater.* **13** (2023) 2300103.
3. B. Voigtlander, *Atomic Force Microscopy*, Springer, (2019).
4. R. A. Dunlap, *Novel Microstructures for Solids*, Morgan & Claypool Publishers, (2018).
5. E. Smith, G. Dent, *Modern Raman Spectroscopy: A Practical Approach*, Wiley, (2019).
6. D. B. Willians, C. B. Carter, *Transmission Electron Microscopy: A Textbook for Materials Science*, Springer, (2009).
7. B. Gault *et al.*, Atom probe tomography, *Nat. Rev. Meth. Prim.* **1** (2021) 51.
8. M. K. Miller, R. G. Forbes, *Atom-Probe Tomography*, Springer, (2014).
9. S. O. Kasap, P. Capper, *Springer Handbook of Electronic and Photonic Materials*, Springer, (2017).
10. C. Schick, R. Androsch, Fast Scanning Calorimetry, in *Thermal Analysis of Polymeric Materials: Methods and Developments Vol. 1*, Wiley, (2022).

B-III – Course details

Course title	**Chemistry and physics of surfaces and interfaces**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	16L + 8l	**Hours**	24	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures, laboratory
Verification	Oral exam				
Guarantor	**prof. Ing. Zdeňka Kolská, Ph.D.**				
Lecture(s)	prof. Ing. Zdeňka Kolská, Ph.D. Dr. rer. nat. Mgr. Jiří Novák				
Syllabus					

The course on surfaces and interfaces provides a fundamental in-depth description of the chemistry and physics of hard and soft surfaces and their interactions with the surrounding environment. It combines two different approaches to describe the subject and to promote the interdisciplinarity of the course. One view is that of chemistry and the other of physics. The former focuses on and describes chemical interactions and surface/interface modifications, while the latter view provides the atomistic origin of surface/interface structures. The theoretical background will further be supported by introducing characterization techniques with a special focus and attention on measuring the physico-chemical properties of surfaces and interfaces. The suggested structure of the course and the topics included are given below. Due to the individual character of the doctoral study, the course structure can be adjusted to suit the student's individual needs for the successful completion of their dissertation thesis.

Theoretical part of the course

The topics covered by the course are, though not limited to:

1. *Introduction and overview of the topic* – surfaces in nature, catalysis, surfaces and interfaces in industry.
2. *Properties of surfaces and interfaces* – phase, phase interphase, definition; surface and interface energy and tension; Bulk and surface crystallography, morphology, super-lattices and superstructures, surface reconstruction and relaxation, electronic structure of surfaces and interfaces, work function, surface energy, lattice vibrations, Langmuir films, phase interface with a curved surface (Laplace Young eq., Kelvin eq. Thomson eq.).
3. *Surface chemistry* – surface charge, surface wettability; electrically charged phase interfaces; theory and determination methods.
4. *Processes at surfaces* – adsorption, desorption, diffusion, nucleation and inter-layer transport; film growth and epitaxy; growth modes; self-organization.
5. *Preparation of Surfaces* – sources of contamination; single crystal surfaces – cleaving and annealing; chemical cleaning; ion sputtering; chemical, physical, physico-chemical methods for the preparation of nanostructured surfaces, changes in surface chemistry, roughness, etc.
6. *Methods of thin-film deposition (physical and chemical deposition techniques)* – vacuum (HV and UHV) technology; molecular beam deposition; chemical vapour deposition; pulsed-laser deposition; sputter deposition; reaction segregation. Wet-deposition techniques – Langmuir-Blodgett technique; spin-coating; printing techniques; dip-coating.
7. *Dispersions* – division and Oralples of dispersion systems, aerosols, suspensions, lyosols, emulsions, gels, physical properties of dispersion systems.
8. *Methods and techniques to characterize interfaces and surfaces*. 1) Diffraction techniques – kinematical description of diffraction; low energy electron diffraction (LEED); geometry of diffraction pattern; diffraction of high energy electrons; surface x-ray diffraction; helium diffraction. 2) Electron spectroscopy – Electron sources, analyzers and detectors; photon sources; element-specific spectroscopy; X-ray photoelectron spectroscopy; core-level shifts; Auger electron spectroscopy; chemical elements analysis; surface band structure analysis. 3) Atomic force microscopy – scanning tunnelling microscopy – topography, tunnel process, spectroscopy, applications. 4) Thermal desorption spectroscopy – principles, types of spectra, evaluation; ion scattering. 5) Ellipsometry – principles, evaluation, and applications. 6) Surface-enhanced Raman spectroscopy (SERS) – principles and applications.

Practical part of the course

As part of the course, students will be offered a practical course (at least one practical should be selected from the list below) to deepen and apply the theoretical knowledge gained. As for the theoretical courses, the complementary chemical and physical approaches are reflected and the characterization of surfaces and interfaces to obtain complex information about a material will be exercised.

Spectroscopic ellipsometry – students will learn how to measure angle-dependent spectra; they will learn how to determine (model) the thickness of thin films; measure and calculate optical functions of transparent, weakly- and strongly-absorbing materials; optical surface roughness, and determine optical bandgap energy for oxide films.

Raman spectroscopy – identification of materials and chemical bounds using a database; comparison of the intensity of Stokes and Anti-Stokes lines of GaAs with the theoretical prediction.

Measuring of Zeta potential – Zeta potential is a characteristic parameter for the description of solid surface chemistry. It is advantageously used as one of the methods for the characterization of various materials giving information about surface chemistry, polarity, swelling and surface charge. It is important for the subsequent adhesion of other materials or as a parameter of stability at dispersions. Zeta potential of several different polymer foils will be determined and compared.

Literature

1. T. Fauster, L. Hammer, K. Heinz, and A. Schneider, *Surface Physics: Fundaments and Methods*, Berlin/Boston: Walter de Gruyter GmbH, (2020).
2. D. Berti and G. Palazzo, *Colloidal Foundations of Nanoscience*, Elsevier, (2021).
3. O. N. Oliviera, L. Caseli, K. Ariga, The past and the future of Langmuir and Langmuir–Blodgett films. *Chem. Rev.*, **122** (2022) 6459.
4. S. J. Yoo, Q-Han Park, Spectroscopic ellipsometry for low-dimensional materials and heterostructures. *Nanophotonics* **11** (2022) 2811.
5. J. Langer *et al.*, Present and future of surface-enhanced Raman scattering. *ACS Nano* **14** (2020) 28.

B-III – Course details

Course title	**Hydrodynamics**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	24L	**Hours**	24	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**doc. Ing. Jaromír Havlica, Ph.D.**				
Lecture(s)	doc. Ing. Jaromír Havlica, Ph.D.				

Syllabus

This course in hydrodynamics explores the principles, theories, and applications of fluid dynamics with an emphasis on its relevance to chemical, biotechnological, and biomedical applications. The course covers the behaviour of fluids under various conditions and introduces students to measurement techniques and modelling approaches for analysing fluid behaviour. Throughout the course, students will learn the fundamental principles and theories of fluid dynamics, including fluid properties, kinematics of fluid motion, conservation laws, and boundary layer theory. They will also study topics such as laminar and turbulent flow. Upon completion of this course, students will have a strong foundation in fluid dynamics and will be able to apply this knowledge to real-world problems in the chemical industry, biotechnology, and biomedical applications. They will also be able to critically evaluate current research and literature in the field and contribute to a deeper understanding of fluid dynamics in these areas.

1. *Fluid properties*: advanced concepts of density, viscosity, surface tension, and other fluid properties that affect fluid behaviour and its interactions with other materials.
2. *Kinematics of fluid motion*: velocity and acceleration, Eulerian and Lagrangian descriptions of fluid motion kinematics.
3. *Conservation laws* - mass, energy, momentum: diffusion and convection, heat and mass transfer, momentum transfer.
4. *Laminar and turbulent flow*: Differences between laminar and turbulent flow, flow patterns in laminar and turbulent flow, Reynolds number, and critical transition.
5. *Mixing and dispersion*: mixing in laminar and turbulent flow, dispersion in fluid systems, optimization of mixing and dispersion in different applications.
6. *Rheology*: viscosity and non-Newtonian fluids, elastic and plastic deformation, applications of rheology in chemistry, biotechnology, and biomedical industries.
7. *Flow behaviour of non-Newtonian fluids*: applications of non-Newtonian fluids in chemical, biotechnological, and biomedical industries, experimental techniques for characterizing non-Newtonian fluids.
8. *Multiphase flows*: two-phase and three-phase flows, applications of multiphase flows in chemical and biotechnological industries.
9. *Applications of fluid dynamics in the chemical industry*: fluid dynamics in chemical engineering processes, transport phenomena, and mixing in chemical processes.
10. *Applications of fluid dynamics in biotechnology*: microfluidic devices and their applications in biotechnology, fluid dynamics in bioreactors, and fermentation processes.
11. *Applications of fluid dynamics in biomedical applications*: fluid dynamics in medical imaging and drug delivery, hemodynamics, and blood flow.
12. *Measurement techniques in fluid dynamics*: introduction to measurement techniques, flow visualization techniques, pressure, and velocity measurement techniques.

Literature

1. P. A. Davidson, *Incompressible Fluid Dynamics*, Oxford University Press, (2022).
2. J. Zierep, K. Bühler, *Principles of Fluid Mechanics Fundamentals, Statics and Dynamics of Fluids*, Springer Fachmedien Wiesbaden, (2022).
3. A. Feldmeier, *Theoretical Fluid Dynamics*, Springer International Publishing, (2020).
4. B. K. Shivamoggi, *Introduction to Theoretical and Mathematical Fluid Dynamics*, Wiley, (2022).

B-III – Course details

Course title	**Ion-beam synthesis and radiation testing of materials for energetic applications**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	16L + 4s	**Hours**	20	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures, seminar
Verification	Oral exam				
Guarantor	**prof. RNDr. Anna Macková, Ph.D.**				
Lecture(s)	prof. RNDr. Anna Macková, Ph.D. Ing. Jan Kameník, Ph.D.				

Syllabus

The course is focused on the principles of modification of materials by ion beam(s), so-called ion implantation. Ion implantation is based on the use of charged particles with known energy, which are implanted into the surface layer of materials. The first part of the course will cover the theory of energy loss of ions, theoretical and semi-empirical description of electron and nuclear ion losses in materials. Depending on the implantation parameters used (ion fluence, ion mass, ion energy, the amount of deposited energy, the amount of dopant and its depth distribution in the material), the resulting modified properties of the surface layer can be controlled with great precision. This also defines the resulting physical properties of a material synthesized by ion beams. The following processes and applications will be emphasized in the course, that is the possibility of using ion-beam irradiation for radiation hardness testing of materials for energetic application, dpa (displacement per atom) evolution in fusion and other related nuclear materials, ion-beam modification of surfaces for applications in solar cells, materials for hydrogen evolution etc.

The course will demonstrate that ion implantation modifies the physical properties of ion-implanted materials due to the disruption of chemical bonds, and the ongoing ionization can lead to the formation of defects, the release of volatile compounds from the material, and different positioning of the dopant in the structure of the irradiated material. All of those result in a change in chemical composition, electron structure, chemical bonds, dynamic changes in the movement of the effects in the material, local deposition of energy, etc.

Focused-ion beam usage for micro- and nanostructures formation will be demonstrated for flexible electronics, energetically and carbon-free favourable materials and technological applications using energetic ions. Monoenergetic ion implantation typically uses charged particle accelerators and ion implanters to produce ion beams, which offer a plethora of combinations of ion types, masses and energies in parallel with specific instrumentation of focused ion beams.

The course contains also a basic description of ion-beam analytical methods used for layered and bulk materials characterization. Main physical principles, quantitative and qualitative analysis of the spectroscopic data from Rutherford Back-Scattering spectrometry (RBS), Elastic Recoil Detection Analysis (ERDA), Particle Induced X-ray Emission spectroscopy (PIXE) and Nuclear Reaction Analysis (NRA) will be described. In the above-mentioned methods, the students will acquire the basics of quantitative and qualitative analysis and knowledge on the evaluation of energy spectra of the above-mentioned ion analytical methods.

Part of the course will be practising in SRIM (Stopping Range and Ions in Matter) and simulations for ion ranges, energy stopping, defect creation and dpa evolution will be realized.

Literature

1. J. W. Mayer, M. Nastasi, Y. Wang, *Ion Implantation and Synthesis of Materials*, Springer Verlag, (2006).
2. H. Ryssel, H. Glawischnig, *Ion Implantation Techniques*, Springer Science & Business Media, (2012).
3. J. F. Ziegler, J. P. Biersack, SRIM – The stopping and range of ions in matter. *Nucl. Instrum. Methods Phys. Res. B* **268** (2010) 1818.
4. D. Fink, *Fundamentals of Ion-Irradiated Polymers, Springer*, Heidelberg, (2004).
5. L. C. Feldmann, J. W. Mayer, S. T. Picraux, *Material Analysis by Ion Channelling*, Academic Press, (1982).
6. J. F. Ziegler, *The Stopping of Energetic Light Ions in Elemental Matter*, Version SRIM - 2012. Available at: http://www.srim.org/ .
7. Accelerator school CERN. Available at http://cds.cern.ch/record/813710/files/CERN-2006- 012.pdf?version=1

8. J. R. Tesmer, *Handbook of Modern Ion Beam Materials Analysis*, Material Research Society, (1995).
9. A. Mackova *et al.*, Damage accumulation and structural modification in c-plane and a-plane GaN implanted with 400 keV Kr and Gd ions. *Surf. Coat. Technol*. **355** (2018) 22.
10. A. Macková *et al.*, Combined Au/Ag nanoparticle creation in ZnO nanopillars by ion implantation for optical response modulation and photocatalysis. *Appl. Surf. Sci.* **610** (2023) 155556.
11. A. Macková *et al.*, Energetic Au ion beam implantation of ZnO nanopillars for optical response modulation. *J. Phys. D* **55** (2022) 215101.
12. P. Malinsky *et al.*, Graphene oxide and polymer humidity micro-sensors prepared by carbon beam writing. *Polymers* **15** (2023) 1066.
13. A. Macková *et al.*, Radiation damage evolution in pure W and W-Cr-Hf alloy caused by 5 MeV Au ions in a broad range of dpa. *Nucl. Mater. Ener.* **29** (2021) 101085.

B-III – Course details

Course title	**Luminescence: From molecules to nanoparticles**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	16L	**Hours**	16	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**Ing. Kamil Lang, CSc., DSc.**				
Lecture(s)	Ing. Kamil Lang, CSc., DSc.				

Syllabus

The course complements and expands the knowledge of students in the field of photophysical and photochemical processes occurring after the absorption of light in molecules with emphasis on luminescence and other photoinduced events in complex (nano)systems. Various systems and their luminescent properties will be analyzed, including upconverting nanoparticles, clusters, aggregates, quantum dots, etc. Emphasis is placed on advanced techniques of UV-vis absorption and luminescence spectroscopy, general application of photochemical laws, description of relaxation of excited states of molecular entities and the trajectory of absorbed energy in nanosystems. Students should get general overview of photoinduced processes, knowledge for qualified analyzes and evaluation of photophysical and photochemical behavior of various systems, and also better understand photoinduced processes that might take place in their own research area.

The course consists of the following parts:

1. Introduction to molecular photophysics and photochemistry: light and its interaction with matter, basic terms, excitation of molecules and their subsequent relaxation, radiative and non-radiative transitions, characterization of photophysical and photochemical processes, quantum yields, photochemical laws and rules.

2. Absorption: Lambert-Beer law and its significance for photophysical and photochemical processes, UV-vis absorption spectroscopy, transient spectroscopy, diffuse reflection spectroscopy.

3. Luminescence I, Introduction: relaxation of excited states, relaxation kinetics, basic rules, importance for analytical chemistry and detection (sensing), effect of solvents, steady-state and time-resolved luminescence spectroscopy, kinetics of luminescence and its analysis, luminescence quantum yields.

4. Luminescence II, Complex processes: quenching of excited states, bimolecular processes, effects of intramolecular rotation, quenching and aggregation induced fluorescence, excimers, exciplexes, resonance energy transfer, photoinduced electron transfer.

5. Nanomaterials: upconverting particles, rare earths, semiconductor crystals and quantum dots, photocatalysis, transition metal clusters, excitation by ionizing radiation.

6. Carbon nanomaterials: carbon dots, nanodiamonds, nanotubes, fullerenes.

7. Analysis of a selected photophysical/photochemical topics and its presentation for course members. Discussion on the selected topics.

Literature

1. Z. Gryczynski, I. Gryczynski, *Practical Fluorescence Spectroscopy*, Taylor & Francis Inc., (2019).
2. J. R. Lakowicz, *Principles of Fluorescence Spectroscopy*, 3rd Ed., Springer, (2006).
3. P. Klán, J. Wirz, *Photochemistry of Organic Compounds: From Concepts to Practice. Postgraduate Chemistry Series*, Wiley, (2009).
4. J. Mei *et al.*, Aggregation-induced emission: Together we shine, united we soar! *Chem. Rev*. **115** (2015) 11718.

B-III – Course details

Course title	**Magnetic properties of functional materials**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	16L	**Hours**	16	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**doc. RNDr. Stanislav Daniš, Ph.D.**				
Lecture(s)	doc. RNDr. Stanislav Daniš, Ph.D.				

Syllabus

The course will focus on fundamental and advanced physical description of magnetic properties of solids, thin films and nanostructures. The course will cover the following topics:

1. Diamagnetism and paramagnetism vs the free electron model, magnetic moments of elements with *d*- and *f*-electrons, the relation between electronic structure and magnetic moment, orbital, spin and total magnetic moment.
2. Interaction of magnetic moments – the interaction of *d*- and *f*-electrons with crystal field, magnetocrystal anisotropy, exchange interactions, and the origin of magnetic ordering (Ising and Heisenberg models).
3. Magnetic ordering – types of magnetic ordering, magnetic structures, magnetic phase transitions, critical phenomena, bulk and surface magnetism.
4. Experimental methods for studying the magnetism of substances – bulk methods, spectroscopic methods, neutron and muon scattering.
5. Observing magnetic domains – magneto-optical methods, transmission-electron microscopy, mechanical microscanning techniques
6. Influence of particle size on magnetic behaviour, domain structure, superferromagnetism (Stoner-Wolhfarth model).
7. New types of magnetic materials – nanomaterials, thin films and multilayers, permanent magnets, antiferromagnetics.
8. Applications of magnetic materials – magnetic recording, targeted drug transport, contrast agents for NMR, applications for sensor design, and removal of contaminants from the environment.

Literature

1. K, B. Tamayo, *Magnetic Properties of Solids (Material Science and Technologies Series)*, Nova Science Publishers Inc., (2009).
2. I. Stoica, A. R. Abraham, A. K. Haghi, *Modern Magnetic Materials: Properties and Applications*, Apple Academic Press Inc., (2023).
3. V. Franco, B. Dodrill, *Magnetic Measurement Techniques for Materials Characterization*, Springer, (2021).
4. A. Hubert, R. Schäfer, *Magnetic Domains, The Analysis of Magnetic Microstructures*, Springer, (2009).

B-III – Course details

Course title	**Materials and living systems**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	24L + 16l	**Hours**	40	**Credits**	20
Course completion	Pre-exam credit, exam			**Teaching type**	Lectures, laboratory
Verification	Pre-exam credit: laboratory protocols Written exam				
Guarantor	**Mgr. Jan Malý Ph.D.**				
Lecture(s)	Mgr. Jan Malý, Ph.D. Mgr. Marcel Štofik, Ph.D.				
Syllabus					

The aim of the course is to provide an overview of the issues and use of so-called Bio-microelectromechanical systems (BioMEMS) and lab-on-chip devices for use in the field of biological sciences and sciences bordering on biology. These technologies, which blend microscale structures with biological components and enable precise fluid manipulation, offer valuable methods for exploring cellular dynamics, biomolecular processes, and innovative diagnostics. By engaging with these topics, students will acquire interdisciplinary skills crucial for addressing complex biological inquiries, designing lab-on-chip devices, and contributing to advancements in genomics, proteomics, drug delivery, and tissue engineering. This integration prepares students to contribute meaningfully to the ongoing developments in personalized healthcare, biotechnology, and related fields.

The main objective is to equip students with essential knowledge and practical experience in the field at the intersection of biology, engineering, and nanotechnology. Students will become familiar with the importance of miniaturization for the development of biological experimental methods and, through practical Oralples, will gain an overview of the possibilities of using Bio-MEMS in applications with different orientations (e.g., cultivation of cell cultures, manipulation of cells, creation of concentration gradients for experiments, surface modifications for immobilization of bioactive substances, preparation of microarrays, etc.).

During the course, students will become familiar with the theoretical principles and at the same time practically master selected techniques from the workflow of Bio-MEMS production using a combination of ion technologies (EBL lithography in the production of masks and in polymer modification, FIB lithography for the finalization of silicon masters and deposition processes, deep reactive ion etching processes (DRIE), optical lithography (UV photolithography, laser lithography), plasma chemical deposition techniques and soft lithography (e.g., NIL) and will perform selected experiments related to the given topic.

The course is divided into the theoretical part and the practical exercise.

<u>Theoretical part</u>

- Origin and development of microfluidic systems, introduction to terms: microfluidic systems, µTAS, Lab-on-a-chip, BioMEMS,
- Production techniques and materials for the preparation of microfluidic devices with an emphasis on the application of ion technologies,
- Basic functional principles of microfluidic systems and selected areas of use in bioapplications.

<u>Laboratory exercises</u>

The practical part will be focused on mastering selected specific Bio-MEMS preparation protocols and subsequent simple experiments performed in devices that will be partially or completely prepared by students. Laboratory protocols will be focused on demonstrating work procedures that are part of the workflow of manufacturing and testing microfluidic systems, e.g.:

- Preparation of system/equipment design – work with modelling/graphics program,
- Preparation of masks for the production of microfluidic devices by electron lithography and laser lithography,

- Preparation and surface modification of substrates for production processes (e.g., plasma modification) and/or for biopatterning,
- Production of templates (forms) for soft lithography using deep reactive ion etching (DRIE) technology,
- Preparation of nanostructures on a silicon master using FIB lithography,
- Preparation of a polymer cast using the NIL method (nanoimprint lithography),
- Finalization of the microfluidic device by controlled bonding processes,
- Simple experiments and tests in prepared devices.

The practical part of the production of the microfluidic chip will be implemented in the Clean Room Laboratory of the Faculty of Science UJEP. Testing will then be carried out in the Tissue Culture Laboratory and the Optical Microscopy Laboratory at UJEP.

Literature

1. E. Iannone, *Labs on chip: Principles, Design, and Technology*, CRC Press, Taylor & Francis Group, (2018).
2. T. S. Santra, *Microfluidics and Bio-MEMS: Devices and Applications*, Jenny Stanford Publishing, (2021).
3. A. Folch, *Introduction to BioMEMS*, CRC Press, (2013).
4. S. Badilescu, M. Packirisamy, *BioMEMS Science and Engineering Perspectives*, CRC Press, (2011).
5. S. S. Saliterman, *Fundamentals of BioMEMS and Medical Microdevices*, John Wiley & Sons, (2010).
6. W. Wang, S.A. Soper, *Bio-MEMS Technologies and Applications*. CRC, (2007).
7. S. Franssila, *Introduction to Microfabrication*, 2nd Ed., John Wiley & Sons, (2010).

B-III – Course details

Course title	**Materials and principles of energy storage and conversion**					
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**		1-2
Course length	24L	**Hours**	24	**Credits**	20	
Course completion	Exam			**Teaching type**	Lectures	
Verification	Oral exam					
Guarantor	**doc. Ing. Jiří Orava, Ph.D.**					
Lecture(s)	doc. Ing. Jiří Orava, Ph.D. prof. Ing. Tomáš Wágner, DrSc. Ing. Tadeáš R. Wangle, Ph.D. prof. Ing. Pavel Janoš, CSc. prof. Spyros N. Yannopoulos					
Syllabus						

In this course, students will learn the principles, advances, and physical and chemical challenges associated with the development of energy storage. Predominantly, batteries have recently attracted great interest as potentially safe and stable high-energy storage systems. However, key issues remain unsolved, hindering full-scale commercialization. The main focus will be on the principles, materials aspects and recycling relevant to batteries, such as currently the liquid-electrolyte 3rd generation Li-ion batteries. Because the field of energy storage and conversion advances very rapidly, the course will closely monitor and follow the latest developments and achievements as, for Oralple, in a couple of years, solid-state batteries may become commercialized and, therefore, their mechanism, challenges, operation principles, sustainability and recyclability should then be covered by the course with great detail. Although the main physical and chemical principles remain mostly unchanged, the development in the field is mostly driven by discovering new emerging materials trying to fulfil and meet the contradictory requirements and trade-off between high density, fast (dis)charging, safety and recyclability at the end of the battery life. Beyond batteries, other major principles driving the EU initiatives in energy may be covered, those are solar cells for energy conversion and phase-change materials for energy storage, or other technologies reflecting the need of the student's research project, such as triboelectric nanogenerators for energy conversion as smart textiles etc. The main focus will be on the materials aspect and the physico-chemical principles of the technologies and philosophies of energy storage and conversion.

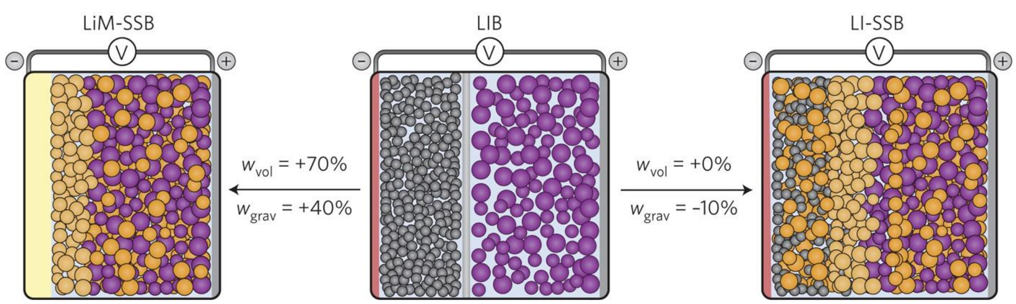

Fig. 1. Typical volumetric and gravimetric energy densities Li-metal solid-state battery (right), in a conventional liquid Li-ion battery (middle) a Li-ion solid-state battery with a conventional anode (right). Image after Janek & Zeiger *Nat. Ener.* **1** (2016) 16141.

The topics covered are:

1. Electrochemical storage systems, battery technology, overview, and review of historical milestones in battery and energy storage research.
2. Fast ionic conductors – ionic conductivity, temperature dependence, Jump model – „hopping model – random walk", activation energy, geometric considerations.
3. Ionic conductivity measurement – AC and DC regime, diffusion coefficient, chemical interpretation.
4. Fast ionic conductors – solid-state electrolytes (SSE), cationic Na^{+}, Li^{+}, proton and anionic (O^{2-}) compounds, conductivity mechanism.
5. Battery materials – SSE, anodes cathodes, a lithium-ion intercalation cell, charging and recharging curves, solid-state electrochemistry.

6. Cathode materials – layered intercalate cathode materials – TiS_2 and $Li_xCo(Mn)O_2$, polyanion oxides, synthesis, challenges.
7. Anodes materials – graphene, Li_3N, LiC_6, Si, MXenes.
8. Solid State Electrolytes – NASICON, LISICON, LIPON, oxides, sulphides, hydrides, halides, borates and phosphate, thin films, polymers, and structure.
9. Polymeric separators and materials – technologies of preparation (electrospinning methods), fire-retardant separators, improving battery safety for thermal management and thermal runaway.
10. Batteries challenges – problems to be solved, battery safety, thermal management, multiscale ion transport on nano-, micro-, meso- and macroscopic scales, electromechanical stresses associated with volume changes.
11. Applications, recent progress and next-generation technologies.
12. Sustainability of the battery industry, recycling processes of the key battery components – challenges and opportunities, 2^{nd} life approach to battery recycling.

Literature

1. R. Korthauer, *Lithium-Ion Batteries: Basics and Applications*, Springer, (2018).
2. K. P. Birke, *Modern Battery Engineering, A Comprehensive Introduction*, World Scientific, (2019).
3. A. R. West, *Solid State Chemistry and Its Applications*, Willey, 2^{nd} edition, (2022).
4. J. Janek and W. G. Zeier, Challenges in speeding up solid-state battery development. *Nat. Ener.* **8** (2023) 230.
5. S. Randau *et al.*, Benchmarking the performance of all-solid-state lithium batteries. *Nat. Ener.* **5** (2020) 259.
6. M. Bates *et al.*, Are solid-state batteries safer than lithium-ion batteries? *Joule* **6** (2022) 742.
7. D. H. S. Tan *et al.*, Carbon-free high-loading silicon anodes enabled by sulfide solid electrolytes. *Science* **373** (2021) 1494.
8. J. Neumann *et al.*, Recycling of lithium-ion batteries—Current state of the art, circular economy, and next generation recycling. *Adv. Ener. Mater.* **12** (2022) 2102917.
9. L. A. Blanquer *et al.*, Optical sensors for operando stress monitoring in lithium-based batteries containing solid-state or liquid electrolytes. *Nat. Commun*. **13** (2022) 1153.
10. *Regulation of the European Parliament and of the Council* concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020.

Online resources:

1. Structures: https://www.chemtube3d.com/lib_lisicon-2/
2. Principles of batteries: https://www.doitpoms.ac.uk/tlplib/batteries/index.php
3. Battery 2030+, Sustainable batteries of the future: https://battery2030.eu/
4. Special issue on Advanced Battery Materials 2030+ published by *Advanced Energy Materials* in 2022: https://onlinelibrary.wiley.com/toc/16146840/2022/12/17

B-III – Course details

Course title	**Materials for tissue engineering and medical use**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	24L + 10l	**Hours**	34	**Credits**	20
Course completion	Pre-exam credit, exam			**Teaching type**	Lectures, laboratory
Verification	Pre-exam credit: laboratory protocols Written exam				
Guarantor	**Mgr. Olga Šebestová Janoušková, Ph.D.**				
Lecture(s)	Mgr. Olga Šebestová Janoušková Ph.D. MSc. Dominika Wrobel, Ph.D. Mgr. Jan Malý, Ph.D. Ing. Stanislav Vinopal, Ph.D. Mgr. Michaela Liegertová, Ph.D.				
Syllabus					

The course brings a theoretical and practical multidisciplinary view of currently studied materials for their medical, biological, or environmental applications. In addition to an overview of state-of-the-art materials and their design, the topic will cover materials' correct application to cells, possible interactions with cells, tissues and the whole organism, including suitable methodologies for studying these interactions based on molecular biological, biochemical, and biophysical methods.

The aim of the course is to provide students with the latest knowledge of biomaterials for predominantly medical uses. The course will cover a description of different types of materials, their physico-chemical properties related to their applications. The course will include a theoretical part comprised of a definition and overview of materials, their interaction with living systems and methods used for their study and application, and their current and emerging applications. In the practical part, the course will focus on advanced characteristics of materials from the medical and biological point of view, for Oralple, viability and cytotoxicity assays, uptake to the cells, stability and storage studies, and aggregation of materials in various physiological solutions will be shown.

Students will acquire knowledge about cells and molecular biology, progressing in biochemistry and biophysical methods. Additionally, macromolecular or polymer chemistry will be covered which relates to biomaterials used. Students will also practise advanced methods of working with cell cultures and perform analysis methods to evaluate the interaction of cells with various materials.

The content of the course will continuously be updated to reflect the latest scientific progress in the field. The suggested structure of the course is as follows.

The theoretical part of the course will cover:

1. Overview of biomaterials, their definition progressing with an advanced description of different types of materials being used, i.e., metals, biopolymers, bioceramics, composites, natural biomaterials and biomimetic materials, materials for tissue engineering, materials for drug delivery, and materials for medical devices.
2. The chemical, physical and biological factors contributing to specific biomaterial choices will be described and correlated with the on-demand applications of materials.
3. Parameters important in the further development of new biomaterials will be introduced. Those include studies of toxicity, biocompatibility, and manufacturing of materials (including the latest developments in modern manufacturing processes, such as additive manufacturing of biomaterials) etc.
4. Selected applications of biomaterials in tissue engineering and regeneration, medical applications, and materials for medical devices will be discussed.
5. The course will also cover description and development methods for the evaluation of interactions between biomaterials and cells.

The practical part of the course will cover:

1. Preparation of materials for „biological evaluation“.
2. Evaluation of the influence of storage conditions on materials' biocompatibility and other relevant properties.
3. Biocompatibility/viability/cytotoxicity assays.
4. Labelling materials and their uptake to the cells.
5. Cultivation of cells to the materials for tissue engineering.

Literature

1. M. Mozafari, J. Rajadas, D. Kaplan, *Nanoengineered Biomaterials for Regenerative Medicine*, 1st Ed., Academic Press, (2018).
2. B. H. A. Rehm, M.F. Moradali, *Biopolymers for Biomedical and Biotechnological Applications*, Wiley, (2021).
3. J. Li, *Biomaterials and Materials for Medicine: Innovations in Research, Devices, and Applications (Illustrated Edition)*, Taylor & Francis Group, (2021).
4. M. C. Tanzi, S. Farè, *Characterization of Polymeric Biomaterials*, Elsevier Science, (2017).
5. H. Hosseinkhani, *Biomedical Engineering: Materials, Technology, and Applications*, Wiley, (2022).

B-III – Course details

Course title	**Materials modelling**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	32L + 8s	**Hours**	40	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures, seminar
Verification	Oral exam				
Guarantor	**doc. RNDr. Marek Malý, Ph.D.**				
Lecture(s)	doc. RNDr. Marek Malý, Ph.D.				
Syllabus					

The course introduces students to the Monte Carlo method (MC), its application in numerical mathematics, and in solving physical problems, including material simulations and calculations of target quantities (properties). Furthermore, students will become familiarized with the Molecular Dynamics method (MD) and its use in particle simulations. The course will also cover related topics and concepts from the area of MD simulations of molecular systems such as empirical force fields, spatial characteristics of the simulated systems, calculation of binding energy, diffusion, etc. The theoretical explanation is supported by solving practical applications, some of which can be implemented by students themselves by using the relevant simulation software.

Monte Carlo

1. Discrete and continuous random variable, basic characteristics and their properties, the law of large numbers, characteristics of the mean of independent random variables, Gaussian distribution, the central limit theorem and its practical use, bootstrap resampling.

2. Generating discrete random variable, general methods for generating continuous random variable (Inverse function method, acceptance-rejection method, superposition method) and special methods for sampling the selected continuous distributions like the Normal or Maxwell–Boltzmann distribution.

3. Fundamental MC algorithms for numerical integration, ways how to increase computation efficiency - methods of variance reduction in numerical integration, discussion of the efficiency of methods: classical or deterministic methods vs. MC with respect to the dimension of the integration domain.

4. Application of the MC method for estimating probability distributions of parameters of complex systems (for Oralple, complex electrical circuits).

5. Solving Laplace's equation using the MC method: theory, basic version - rectangular grid, efficiency increase - random step, comparison with the classic (deterministic) numerical approach.

6. Metropolis algorithm - discrete systems: motivation, theoretical explanation (Markov chain, transition probabilities, transition matrix, detailed balance, microscopic reversibility), demonstration of the Ising model of a ferromagnet, including the calculation of characteristic quantities, Hastings' generalization of the Metropolis method (Metropolis-Hastings algorithm).

7. Metropolis algorithm – continuous systems: - theoretic transition from discrete to continuous systems, sampling of arbitrary probability distributions using Markov chains, tuning of probability distribution parameters for proposing candidates for the next members of the Markov chain (acceptance ratio), numerical integration using the Metropolis algorithm, Simulated annealing optimization method and its application, use of MC in molecular simulations.

8. Transport problem - scattering processes, effective cross-section, mean free path, random free path, methods for efficiency enhancement or the possibility of application to inhomogeneous materials.

Molecular Dynamics

1. Position vector, velocity, acceleration. Newton's second law of motion/equation of motion. Numerical methods for solving equations of motion: Verlet's algorithm, Velocity Verlet's algorithm. Methods applicable when force depends on velocity: Euler's algorithm, Euler-Richardson method.

2. Temperature and pressure control in MD simulations (thermostats, barostats).

3. Model of the potential energy of a molecular system (force field). Atom types, bond and non-bond interactions, their theoretical models, methodologies for obtaining force field parameters, partial charges and methods of their calculation.

4. Diffusion, calculation of the diffusion constant using MD simulation.

5. Simulations with periodic boundary conditions. Motivation, basic idea, particle motion in periodic conditions, calculation of short-range and long-range interactions.

6. Simulation of molecular systems in explicit and implicit solvents (Generalized Born Implicit Solvent), comparison of efficiency for different types of molecular systems.

7. Spatial characteristics: Radial Distribution Function, Pair Distance Distribution function, Radius of Gyration, RMSD

8. Calculation of interaction (binding) energy: Principles of MMPBSA/MMGBSA and Thermodynamic integration methods.

Literature

1. R. H. Landau, M. J. Páez, C. C. Bordeianu, *Computational Physics, Problem Solving with Computers*, 2nd Ed., Wiley, (2007). Available online. https://isidore.co/CalibreLibrary/Landau,%20Rubin%20H_/Computational%20Physics_%20Problem%20Solving%20With%20Computers%20(5402)/Computational%20Physics_%20Problem%20Solving%20Wit%20-%20Landau,%20Rubin%20H_.pdf
2. R. H. Landau, M. J. Páez, *Computational Problems for Physics With Guided Solutions Using Python*, CRC Press, (2018).
3. W. L. Dunn, J. K. Shultis, *Exploring Monte Carlo Methods*, 2nd Ed., Elsevier Science, (2022).
4. A. Bunker, T. Róg, Mechanistic understanding from molecular dynamics simulation in pharmaceutical research 1: Drug delivery. *Front. Mol. Biosci*. **7** (2020) 604770.
5. R. H. Landau, M. J. Páez, C. Bordeianu, *Computational Physics, Problem Solving with Python*, 4th Ed., Wiley, (2024). http://sites.science.oregonstate.edu/~landaur/Books/CPbook/

B-III – Course details

Course title	**Materials under extreme conditions**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	22L	**Hours**	22	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures
Verification	Oral exam				
Guarantor	**Ing. Anna Knaislová, Ph.D.**				
Lecture(s)	Ing. Anna Knaislová, Ph.D. Ing. Tadeáš R. Wangle, Ph.D.				

Syllabus

The course focuses on the description of the chemical and physical properties of a wide variety of materials (metals, glasses, ceramics, polymers…), and their use under extreme conditions and in harsh environments. The application of such materials is in various industries (semiconducting, additive manufacturing), biomaterials (implants), in environmental applications (sensing). The extreme conditions may include high temperature, high pressure, high mechanical stress and loads (fatigue and creep), extremely corrosive environments (including body fluids) and environments full of chemicals and toxic gasses. The extreme environment of high radiation fields (tomography devices, space, nuclear – fusion and fission – industry) will be explored as well. This will be discussed for specific well-studied Oralples. Students will learn the relationships between atomistic and physico-chemical changes in materials exposed to different conditions, they will understand the mechanisms, how to control them, and how to select materials based on the expected operational conditions.

The topics explored will be:

1. Materials exposed to high pressures, temperatures and deformation.
2. Materials for extremely corrosive environments.
3. Materials for chemically active environments.
4. Polymeric nanocomposites for structural applications.
5. Glass and glass-ceramic composites for extreme conditions (vacuum and high-temperature applications).
6. Hard protective coatings for tribological applications.
7. Intermetallics and alloys for high-temperature applications.
8. Borides, carbides, nitrides and their applications for extreme conditions.
9. High-temperature ceramics.
10. Materials under radiation.
11. Extreme plastic deformation of materials.

Literature

1. A. K. Tyagi, S. Banerjee, *Materials Under Extreme Conditions: Recent Trends and Future Prospects*, Elsevier, (2017).
2. R. Bini, V. Schettino, *Materials Under Extreme Conditions*, World Scientific, (2014).
3. R. J. M. Konings, *Comprehensive Nuclear Materials*, 2nd Ed., Elsevier, (2020).
4. S. Eswarappa Prameela *et al.*, Materials for extreme environments. *Nat. Rev. Mater.* **8** (2023) 81.
5. D.K. Schreiber *et al.*, Materials properties characterization in the most extreme environments. *MRS Bulletin* **47** (2022) 1128.

B-III – Course details						
Course title	**Microbiology in material research**					
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**		1-2
Course length	24L + 10l	**Hours**	34	**Credits**	20	
Course completion	Pre-exam credit, exam			**Teaching type**	Lectures, laboratory	
Verification	Pre-exam credit: laboratory protocols Oral exam					
Guarantor	**prof. RNDr. Milan Gryndler, CSc.**					
Lecture(s)	prof. RNDr. Milan Gryndler, CSc.					
Syllabus						

Biomaterials used in medical and industrial applications are exposed to microorganisms present in the environment or can come into contact with communities of microorganisms during the application processes. At the same time, some of these materials may be potentially biodegradable and may be thus prone to microbial deterioration not only causing the loss or undesirable alteration of function, but also constituting a source of contamination of industrial processes or infections in medical use. Expertise in biomaterial research thus should involve the knowledge of methodology used in the detection, identification and cultivation of microorganisms interacting with biomaterials. This represents a prerequisite for controlling the incidence of microorganisms in biomaterials that is, in turn, necessary for reliable and safe applications. Contemporary procedures of detection and identification of microorganisms, as well as the studies of microbial communities, mostly rely on advanced molecular methods needing complex skilful approaches. Similarly, the successful use of disinfectants and modern processes of antimicrobial functionalization and sterilization of biomaterials demand information on the compatibility of the treatment with treated material. These aspects are thus indispensable components of application-oriented material research.

The objective of the course is to provide students with information on material microbiology as well as an overview of methods and approaches used in studies of microbial communities that can be potentially associated with biomaterials and can interact with their mechanical structure or biological function. The processes of deterioration and biofilm behaviour will be tract as well as the potential tools that can be used in controlling the development of microorganisms in the environments of interest. The students will be trained in aseptic works with microbial cultures, in isolation of microbes from material and surfaces, in treatment and sequencing DNA, in DNA sequence-based identification of microorganisms and in methods of disinfection and sterilization. A possibility to discuss and resolve some microbiological problems connected with the student´s own research project is provided.

By attending this course, students will acquire a set of skills and knowledge about the microbiology of biomaterials and methods that can be used in studies of interactions between microorganisms and various types of biomaterials, necessary for successful work in the development of these rapidly evolving products. The knowledge and skills will be acquired by responding to the questions connected with different aspects of material microbiology. The questions to be answered within the frame of the course are provided below.

1. Detailed Understanding of Principles of Microbiology of Biofilms and Microbial Mats: How biofilms and microbial mats develop. What are their biological traits? Why are they so important in nature, in industry, in medicine and in health care? Biofilms are ubiquitous but difficult to study – which are the methods recently in use? How to produce the biofilm *in vitro* and how to quantify it?

2. Microorganisms in Culture: Why so many microorganisms cannot be cultivated ("great mystery of environmental microbiology")? The art of isolation. Where the cultivation-based approach and cultivation-independent approaches are relevant? How to evaluate the diversity of microbial communities in a laboratory and in nature? Why does the diversity matter?

3. Bioinformatics – a lighthouse in the ocean of biological information: What are the benefits and pitfalls of data produced by next generation sequencing platforms? Big data as "standard" type of information in biology of microbial communities – how can we use it? How to use molecular identifiers and why? Which are the biases introduced by PCR process?

4. How to Make the Microorganisms Absent: Which methods of sterilization are appropriate for the material of interest? Chemical versus thermal sterilization versus irradiation versus filtration. Partial sterilization - where it is relevant? Can some microorganisms survive (efficiency of sterilization procedure)? How to check the sterility?

5. Modern Antimicrobial Means: Which modern principles are exploited to reduce or suppress microorganisms? Why are we successful only partially? Never-ending story – is the research on antimicrobial compounds a hope for future?

In general, the course represents a deep insight into the aspects of microbial life that can substantially affect the applicability of different biomaterials in the real world and should be taken seriously into account by anyone who intends to work in this field.

The course is divided into two parts – theoretical and practical.

Theoretical part

1. Microbial contamination and effects of microorganisms on materials. In this section, the interactions of materials of different types with microorganisms will be described and characterized. The problems with decontamination and sterilization will be introduced in the context of material physical and chemical properties. Sub-sections are:
    - Biofilms,
    - Biodeterioration,
    - Clogging, microbial mats, production of odours and harmful compounds,
    - Microbial contaminants in medical materials and tissue replacements,
    - Microorganisms as sources of aggressive chemicals.
2. Molecular analysis of microbial communities in materials and in the environment. This section will be dedicated to the methodology of microbiological studies of microorganisms colonizing materials in industry and medicine. Sub-sections are:
    - Cultivation-dependent versus cultivation-independent methods,
    - Environmental DNA isolation and use,
    - Next-generation sequencing: advantages and limitations,
    - qPCR and its limitations,
    - Signature fatty acids.
3. Friends or enemies? This section will bring information on the possibility of influencing microbial activities in the environment. The sub-sections are:
    - Sterilization of materials,
    - Antimicrobial compounds – types, modes of action, resistance,
    - Antimicrobial materials,
    - Antimicrobial surfaces,
    - Electroactive antibacterial materials.

Practical part

1. Microorganisms in culture.
    - Observation, isolation, and maintaining the isolates,
    - Biofilms in the laboratory: formation and quantification on artificial surfaces,
    - Microbial production of organic acids,
2. Molecular characterization of microorganisms.
    - Specific PCR,
    - Editing the sequencing data,
    - Overview on bioinformatics.
3. Testing the sensitivity of microorganisms to bioactive compounds.
    - Sensitivity to antibiotics – zone test,
    - Disinfectants: microbial survival in a liquid environment.

Literature

1. S. Duan *et al.*, Multifunctional antimicrobial materials: From rational design to biomedical applications. *Prog. Mater. Sci.* **125** (2022) 100887.
2. J.W. Li *et al.*, Electroactive materials: Innovative antibacterial platforms for biomedical applications. *Prog. Mater. Sci.* **132** (2022) 101045.
3. F.C.M. Lobo *et al.*, An overview of the antimicrobial properties of lignocellulosic materials. *Molecules* **26** (2021) 1749.
4. L. Madej-Kiełbik *et al.*, Biodegradable nonwoven materials with antipathogenic layer. *Environments* **9** (2022) 79.
5. M. Martí *et al.*, Antimicrobial characterization of advanced materials for bioengineering applications. *J. Vis. Exp.* **138** (2022) e57710.
6. N. S. Nemes *et al.*, Antimicrobial activity of cellulose based materials. *Polymers* **14** (2022) 735.
7. W. van Rensburg *et al.*, Creating robust antimicrobial materials with sticky tyrocidines. *Antibiotics-Basel* **11** (2022) 174.
8. G. D. De Toledo *et al*., Promising nanostructured materials against enveloped virus. *Aanais de Academia Braileira de Ciencias* **92** (2020) 20200718.
9. Z. Zhen *et al*., Novel functional materials with active adsorption and antimicrobial properties. *Mater. Lett.* **89** (2012) 19.
10. K. M. Dobosz *et al.*, Green materials science and engineering reduces biofouling: Approaches for medical and membrane-based technologies. *Front. Microbiol.* **6** (2015) 196.
11. M. F. Moradali *et al*., Bacterial biopolymers: From pathogenesis to advanced materials. *Nat. Rev. Microbiol.* **18** (2020) 195.
12. Z. Wang *et al*., Dental materials with antibiofilm properties. *Dent. Mater.* **30** (2014) e1.

B-III – Course details

Course title	**Porous materials**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)			**Recommended year**	1-2
Course length	14L + 6l	**Hours**	20	**Credits**	20
Course completion	Exam			**Teaching type**	Lectures, laboratory
Verification	Oral exam				
Guarantor	**RNDr. Jan Demel, Ph.D.**				
Lecture(s)	RNDr. Jan Demel, Ph.D.				

Syllabus

The course complements and expands students' knowledge in the field of materials chemistry and the chemistry of nanoparticles. The lectures will explain how the presence of pores in a material influences material's macroscopic properties and how pore space can be used in some applications such as heterogeneous catalysis or adsorptions. The aim is to provide a comprehensive overview of what can be expected from materials containing a certain type, size and distribution of pores.

The course will cover the following topics:

1. Overview of the topic, definition of materials and their pores, and history of porous materials from natural zeolites to synthetic molecular sieves.
2. Methods for characterization of porous materials.
3. Categorization of porous materials according to chemical nature (zeolites, AIPO, carbon-based materials, MOFs, etc.).
4. Preparation of porous materials and their modifications.
5. Unique phenomena that have been described on porous materials (breathing effect, negative gas adsorption).
6. Usage of porous materials in the laboratory and industry.
7. Modern research trends of porous substances including porous liquids.
8. Practical – sample preparation and measurement on sorption instruments (ÚACH).

Literature

1. Pascal van der Voort, Karen Leus, and Els de Canck, *Introduction to Porous Materials*. Wiley, (2022).
2. V. F. Yusuf, N. I. Malek, S. K. Kailasa, Review on metal–organic framework classification, synthetic approaches, and influencing factors: Applications in energy, drug delivery, and wastewater treatment. *ACS Omega* **7** (2022) 44507.
3. C. Candia-Onfray *et al.*, An updated review of metal–organic framework materials in photo(electro)catalytic applications: From CO_2 reduction to wastewater treatments. *Curr. Opin. Electrochem*. **26** (2021) 100669.
4. A. Thomas, Much ado about nothing – a decade of porous materials research. *Nat. Commun*. **11** (2020) 4985, references therein.
5. V. Sharma *et al.*, A comprehensive review on the synthesis techniques of porous materials for gas separation and catalysis. *Can. J. Chem. Eng.* **100** (2022) 2653.

B-III – Course details

Course title	**Powders and granular materials**				
Type	B. Povinně volitelné teoretické kurzy (Compulsory optional courses)		**Recommended year**	1-2	
Course length	22L	**Hours**	22	**Credits**	20
Course completion	Exam		**Teaching type**	Lectures	
Verification	Oral exam				
Guarantor	**doc. Ing. Jaromír Havlica, Ph.D.**				
Lecture(s)	doc. Ing. Jaromír Havlica, Ph.D.				

Syllabus

This course is an advanced study of granular materials, focusing on the fundamental concepts, behaviour, and applications of powders and granulated substances in various industrial and natural contexts. The curriculum delves into the statics and dynamics of granular systems, flow and rheology, segregation, jamming, and measurement techniques. Students will also explore modelling approaches, the role of granular materials in the circular economy, and their use in renewable energy systems. By the end of the course, participants will have gained a deep understanding of granular materials, preparing them for cutting-edge research and applications in diverse fields such as geotechnical engineering, pharmaceuticals, food processing, and renewable energy.

1. *Definition of powders and granular materials*: an overview of powders and granular materials, particle size distribution, and packing of particles.
2. *Statics and dynamics of granular materials*: forces on particles in a granular system, stress, and strain in granular materials, contact mechanics of particles.
3. *Flow and rheology of granular materials*: flow regimes of granular materials, the flow of granular materials in silos and hoppers, and rheology of granular materials.
4. *Segregation in granular materials*: causes of segregation, segregation mechanisms, models for predicting segregation.
5. *Jamming in granular materials*: definition of jamming, jamming transition in granular materials, jamming and unjamming processes.
6. *Measurement techniques for granular materials*: particle imaging techniques, particle tracking techniques, and bulk measurement techniques.
7. *Modelling approaches for granular materials*: discrete element method, continuum models, microscopic models.
8. *Applications of granular materials in industry*: handling and processing of powders, granular materials in geotechnical engineering, granular materials in pharmaceuticals, and food processing.
9. *Applications of granular materials in natural phenomena*: granular materials in landslides, sediment transport in rivers and coastal environments, granular materials in avalanches and sand dunes.
10. *Principles of circular economy*: granular materials and circular economy, case studies.
11. *Granular materials in renewable energy*: use of granular materials in solar and wind energy systems, optimization of granular materials in renewable energy systems, case studies of granular materials in renewable energy systems.

Literature

1. B. Andreotti, Y. Forterre, O. Pouliquen, *Granular Media: Between Fluid and Soli*d, Cambridge University Press, (2013).
2. H. Makino, K. Higashitani, S. Matsusaka, *Powder Technology Handbook*, CRC Press, (2019).
3. E. Guyon, J.-Y. Delenne, F. Radjai, *Built on Sand*, MIT Press, (2022).
4. A. Hassanpour, C. Hare, M. Pasha, *Powder Flow Theory, Characterisation and Application*, RSC Publishing, (2019).
5. A. J. Hickey, S. Giovagnoli, *Pharmaceutical Powder and Particles*, Springer International Publishing, (2018).
6. G. Mortara, P. M. Mariano, P. Giovine, *Views on Microstructures in Granular Materials*, Springer, (2020).