DOCTORATE IN SCIENCES AND TECHNOLOGIES OF CHEMISTRY AND MATERIALS

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Design and synthesis of protein–kinase inhibitors as anticancer agents

Teacher: Prof. Anna Carbone, Prof. Michele Tonelli (UniGe, Dipartimento di Farmacia).

Overview
Protein kinases have become one of the most important drug targets for antitumor therapy in the 21st century. Notably, 70 of the FDA-approved KIs are used in targeted cancer therapies. Despite their advantages compared to traditional chemotherapy, KIs face significant limitations. Only a fraction of the entire kinome has been targeted so far, and this offers the prospect for further advancements in kinase inhibition strategies, such as identifying new targets, addressing drug resistance, and overcoming the blood–brain barrier penetration. The future of kinase-targeted drugs in cancer is still promising, and implementation of these strategies may help to improve current treatment liabilities.

Contents
• Cancer: classical and targeted chemotherapy. Phenomenon of resistance to chemotherapy.
• Classification of protein kinases (PTKs), structural characteristics, functions and signal transduction pathways.
• Classification of protein kinases, structural features, functions and signal transduction pathways.
• Classification of tyrosine kinase inhibitors.
• Design and synthesis strategies of drugs directed against receptor tyrosine kinases (RTKs) and analysis of molecular ligand/protein interactions.
• Design and synthesis strategies of drugs directed against cytoplasmic protein kinases (NRTKs) and analysis of ligand/protein molecular interactions.

CFU: 2

Indicative period: Mar-Apr-May-Jun

Contact teacher email: michele.tonelli@unige.it

Drug Discovery: an introduction to the process leading to new small-molecule drugs

Teachers: Dr. Andrea Armirotti (IIT, Analytical Chemistry Facility), Dr. Fabio Bertozzi (IIT, Computational & Chemical Biology), Dr. Sergio Decherchi (IIT, Data Science & Computation Facility); Dr. Stefania Girotto (IIT, Structural Biophysics Facility), Dr. Benedetto Grimaldi (IIT, Molecular Medicine), Dr. Debora Russo (IIT, Structural Biophysics Facility), Dr. Rita Scarpelli (IIT, Medicinal Chemistry and Technologies for Drug Discovery and Delivery Facility), Dr. Marina Veronesi (IIT, Structural Biophysics Facility); Dr. Pietro Vidossich (IIT, Molecular Modeling and Drug Discovery).

Overview
The course describes the process leading to the approval of a new chemical entity as a drug. This process develops through the discovery phase, the preclinical development, and the clinical development. The focus of the course is on the discovery phase, which consists of four steps: target identification and validation, hit identification, hit to lead, and lead optimization. Activities performed in each of the four steps are described to illustrate the multidisciplinary approach of the process and the technologies for the search and characterization of the candidate drug.

Contents
• Drug discovery and drug development phases.
• Target identification and validation: source of new targets, target validation studies.
• Hit identification by screening: principle of pharmacology, cell-based vs. cell free assays, choice, development and validation of screening assays.
• Hit identification by Structural Biophysics methods: NMR, SPR, ITC, MST.
• Hit identification using Chemical Libraries: type of compound libraries.
• Hit to Lead and Lead Optimization: SAR, drug-likeness and strategies to improve it, bioisosterism.
• Bioanalytical Tools for compound characterization: identification and quantitation of exogenous compounds in biological environments.
• Hit to Lead and Lead Optimization: docking, molecular simulations and free energy calculations, calculated properties and drug likeness.

CFU: 2

Indicative period: May

Contact teacher email: benedetto.grimaldi@iit.it

Electrochemistry for energy storage and conversion: theory and applications

Teachers: Dr. Michele Ferri (IIT, Nanochemistry & CSO at Antares Electrolysis S.r.l.), Dr. Marco Ricci (IIT, Delta Lab).

Overview

Electrochemistry as an experimental discipline dates back to 1800, when Alessandro Volta invented the first electrochemical cell, the Voltaic pile. Since then, it has evolved into one of the most influential branches of physical chemistry, providing the scientific foundation for technologies ranging from batteries and fuel cells to corrosion protection, electroplating, electrocatalysis, and electrochemical synthesis. This course introduces the fundamentals and applications of electrochemistry. Specifically, in the first part, the students will be introduced to modern electrocatalysis and its role in the ongoing energy transition, with emphasis on experimental practices (methodology, instrumentation, data interpretation, and benchmarking), as well as brief coverage of electrochemical engineering and process scale-up toward industrial implementation. The second part provides an overview of the history of electrochemical energy storage, with a primary focus on rechargeable batteries. It introduces the fundamental principles of battery science, including battery operation, thermodynamics, kinetics, charge-storage mechanisms, materials, electrolyte design, and device architecture. The course also covers the fundamentals of battery manufacturing, from electrode preparation and cell assembly to industrial production, and concludes with laboratory demonstrations on battery fabrication and electrochemical characterization. Drawing from both academic research and industrial experience, the course bridges the gap between fundamental science and real-world deployment of electrochemical technologies for sustainable energy and chemical production.

Contents

Electrochemistry and applications to energy conversion

• Fundamentals of electrochemistry: key concepts, definitions, and governing equations.
• Introduction to catalysis and electrocatalysis: fundamental principles, historical development, and the current industrial and energy-related relevance of electrocatalytic technologies.
• Laboratory-scale electrocatalytic testing: catalysts, experimental techniques, instrumentation, data interpretation, and considerations for industrial relevance.
• Scale-up of electrocatalytic processes: basic principles of electrochemical engineering and the transition from laboratory systems to industrial implementation.

Battery Science: Fundamentals, Materials, and Devices

• Historical overview of electrochemical energy storage.
• Physical chemistry of batteries.
• Battery components.
- Focus on active materials: working principles and selection.
- Focus on electrolyte design and solvation chemistry.
• Battery performance metrics and characterization techniques.
• Research frontiers in battery technology.
• Laboratory session: battery fabrication and characterization.
• Critical analysis of battery research: critical evaluation of scientific literature, experimental design, data interpretation, pitfalls and sources of error, case studies from recent battery research.

CFU: 2

Indicative period: Mar-Apr

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Electronic structure of solids

Teacher: Prof. Liberato Manna (IIT, NanoChemistry).

Overview
The course provides and overview of the electronic structures in solids, combining the free and quasi-free electron models with a molecular orbital approach, in 1, 2 and 3 dimensions. The course also covers an extensive set of examples of materials and dimensionalities. The overall scope is to provide a common language and key concepts to students with different types of backgrounds (chemistry, physics, materials science).

Contents
- Crystals and lattices.
- Free and nearly free electron models, density of states, Fermi surface.
- Bonding in simple metals, cohesion.
- Tight binding treatment of homopolar diatomic molecules.
- Tight binding treatment of a linear chain of atoms.
- 2D homopolar lattice.
- 3D homopolar lattice.
- The polar covalent bond and 2D heteropolar lattices.
- Bands from p orbitals and from combinations of s and p orbitals.
- Examples of band structures.
- Bands from d orbitals.
- Ionic bonding.
- Bonding in transition metals and transition metal oxides.
- Effect of electron repulsion.

CFU: 3

Indicative period: Sep

Contact teacher email: liberato.manna@iit.it

Introduction to nanophotonics and nanofabrication

Teacher: Prof. Maria Caterina Giordano (UniGe, Dipartimento di Fisica).

Overview
The objective of this course is to give an overview on the emergent metasurfaces and nanomaterials with application in nanophotonics. Peculiar light matter interaction phenomena at the nanoscale such as biomimetic effects, plasmonic resonances, and photonic anomalies will be discussed. The peculiar optoelectronic properties of the emergent layered 2D materials and heterostructures will be introduced. In the second part of the course the nanofabrication processes and characterization techniques which are at the basis of the scientific and technological advancements in nanotechnology and nanophotonics will be shown.

Contents
• Introductory concepts: nanoscience & nanotechnology.
• Biomimetic effects.
• Plasmonic nanoantennas.
• Flat-optics.
• 2D materials: semimetals, semiconductors and insulators. Van der Waals heterostructures. Optoelectronic, photonic properties and energy conversion.
• Modeling of the electronic properties of 2D materials and heterostructures (in collaboration with Dr Damiano Marian (UNIPI)).
• Main top-down nanofabrication approaches: Optical Lithography – Electron beam Lithography - Focused Ion Beam lithography – Laser interference Lithography – thermal Scanning Probe Lithography.
• Technological processes: spin coating, etching, lift off, thin film deposition.
• Main bottom–up nanofabrication approaches: self–assembly and self–organization.
• Morphological nanoscale characterization of nanostructures and nanomaterials by scanning probe microscopy and scanning electron microscopy.
• Optical characterization of nanostructures and nanomaterials by far–field optical spectroscopy (e.g. optical transmission, reflection) and scanning near–field optical microscopy.
• Laboratory session on nanofabrication and optical characterization of nanomaterials.

CFU: 3

Indicative period: Mar-Apr-May-Jun

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Molecular markers of food quality and genuineness

Teachers: Prof. Raffaella Boggia, Prof. Federica Turrini (UniGe, Dipartimento di Farmacia).

Overview
The course will explore various aspects of research in food chemistry, with a particular emphasis on identifying innovative markers of quality and authenticity for foods of both plant and animal origin, and comparing these with traditional markers. Several case studies will be presented, focusing on specific categories of foods, including those designed for particular groups of people, dietary supplements, novel foods, and foods with nutritional and health claims.

Contents
• What do food quality and genuineness mean?
• What are quality and genuineness markers?
• Traditional vs. Innovative Analytical Markers
• Legislation
• Case Studies:
- EVO Oils and Gourmet Oils
- Milk & Infant Formulas
- Pomegranate Juices
- Dietary Food Supplements
- Novel Foods

CFU: 2

Indicative period: Jun

Contact teacher email: raffaella.boggia@unige.it

Multivariate analysis of chemical data

Teachers: Prof. Monica Casale (UniGe, Dipartimento di Farmacia).

Overview
The course provides an introduction to and in-depth exploration of the principal techniques of multivariate data analysis. Core topics include principal component analysis (PCA), classification and class modeling methods, as well as multivariate calibration techniques.
The course aims to provide the necessary theoretical background to process complex chemical data and extract useful information from it. Additionally, it emphasizes the practical aspects related to the development and application of chemometric strategies, such as the construction of predictive classification or regression models using multivariate analysis software.

Contents
• Basics of univariate analysis.
• Explorative method: Principal Component Analysis (PCA).
• Classification/Modeling methods: Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA).
• Multivariate Calibration: Multiple Linear Regression (MLR), Partial Least Squares (PLS).

CFU: 3

Indicative period: Jan-Feb

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Organic materials for photonics

Teacher: Prof. Davide Comoretto (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
This class provides basic concepts of light-matter interaction and spectroscopy in organic materials and polymers. After a review of the complex refractive index and its anisotropy characterizing organic materials and how it can be chemically tuned and controlled, fundamental findings on refraction, transmission, reflection and diffraction will be reported. Finally, application to polymer photonic crystals and metamaterials will be discussed.

Contents
• Introduction
• Optional: (Basic Mathematics with vectors operations, complex numbers and Euler's Formula)
Refractive index
• Propagation in dielectrics and metals: Lorentz oscillator and Free electron models.
• Complex refractive index and optical properties: interface and bulk effects.
• Optical anisotropy and birefringence.
• Optical response of organic materials (molecular, polymeric, hybrid, photochromic,…).
• How chemistry can modify and tune the refractive index in organic materials.
Photonic crystals
• Dielectric lattices.
• The role of the dielectric contrast (refractive index in polymer and inorganic dielectrics).
• Growth of photonic crystals: top-down vs. bottom-up.
• Natural (biological and mineral) photonic crystals.
• Structural color.
• Bulk photonic crystals: properties and applications (sensing, design,…).
• Structural defects: waveguides and microcavities. Properties and applications (Laser, optical switch,…).

CFU: 2

Indicative period: May-Jun-Jul-Sep

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Patent and bibliographic databases searching in medicinal chemistry

Teachers: Prof. Chiara Brullo, Prof. Andrea Spallarossa (UniGe, Dipartimento di Farmacia).

Overview
Aim of this course is to get a good level of knowledge and expertise in the use of the principal patent and bibliographic research databases in chemistry and medicinal chemistry, thus all resources will be fully described, some search examples will be showed, and students will test their ability during specific hands–on sessions.

Contents
• Searching strategies consulting Unige chemistry, medical and medical-pharmaceutical resources (Uno per tutti and related Unige resources).
• Pubmed, Scifinder and Reaxys platforms; for these databases additional practical exercises will be also performed for each student.
• Searching strategies on Scopus, Web of Science, clinical trials and patent office databases.
• Searching on cross-linked scientific databases of medical-pharmaceutical interest: PubChem, Protein Data Bank, Uniprot, DrugBank, Aifa database, Natural Compounds database.
• Additional on–line platforms used in patent research and drug design campaigns.
A final practical exam, focused of some selected databases, will be performed by each student.

CFU: 2

Indicative period: Jun

Contact teacher email: andrea.spallarossa@unige.it

Perspectives on bioinorganic chemistry

Teacher: Prof. Serena De Negri (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
This course aims to provide PhD students with an overview on different types of metal-containing inorganic compounds relevant to biological systems, their functions and the related experimental techniques/approaches. Many aspects of inorganic chemistry are addressed in the bio-inorganic studies, such as solution chemistry, coordination chemistry and solid state/materials chemistry, making this topic interesting for different research fields. Moreover, biological processes, showing high efficiency in mild conditions, can serve as models for different problems of modern chemistry, including efficient energy collection and storage and catalytic activation of inert substances.

Contents
• General principles of bioinorganic chemistry: historical background, occurrence, availability and biological functions of inorganic elements, biological ligands for metal ions.
• Some experimental techniques for the study of bioinorganic compounds (ex. XAS and EPR). Model compounds and their utility.
• Biological functions of the alkaline and alkaline earth metal cations. Biomineralization: the assembly of advanced inorganic materials in biology. Examples of biominerals (sulfates, amorphous silica, iron biominerals, calcium carbonate, calcium phosphate).
• Bioinorganic chemistry of transition elements with particular attention to relevant biomolecules of Fe, Co, Ni, Cu and Zn. Description of a few important processes involving transition metal compounds:
-Metals at the centre of photosynthesis (Mg and Mn)
-Metalloenzymes in the biological nitrogen cycle (nitrogen fixation: Fe, Mo, V)
-Metallo-biomolecules containing Fe, Cu for absorption, transport and storage of the oxygen molecule.

CFU: 2

Indicative period: Apr-May

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Polymeric nanocomposites

Teacher: Prof. Orietta Monticelli (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
The aim of the teaching is to learn methods for the preparation, characterization and application of polymer nanostructured systems by discussing some specific examples. The main objective of the teaching is to extend the previous knowledge in chemistry, physics, mathematics as well as materials science acquired by the PhD students during their Master courses to a more specific field where these knowledges can be applied, namely that of nanostructured polymeric materials. In particular, the constant interaction with the students will provide the opportunity to discuss how both their previous knowledge and the PhD students' specific projects can be used in the above field.

Contents
General features of polymer–based nanostructured materials. Type of nanofillers. Methods used for the preparation of polymer nanocomposites. Layered silicates: structures and properties. Modification of layered silicates. Anionic clay, layered phosphates and sepiolites. Type of nanocomposites. Characterization techniques: X–ray diffraction, transmission electron microscopy (TEM) and atomic force microscopy (AFM). Preparation of nanocomposites based on layered silicates: in–situ polymerization (examples: polyamide 6 and polystyrene) and melt–blending. Nanocomposite properties: permeability (Nielsen's model), mechanical properties (Halpin–Tsai's model), thermal and combustion properties.
Examples from the literature will be used to stimulate students' critical sense and the way to critically analyze scientific articles. The examination, which involves writing a short research project according the guidelines of a European call proposal, aims to develop the PhD students' ability to describe new ideas in an exhaustive and convincing way.

CFU: 2

Indicative period: Jan-Feb

Contact teacher email: orietta.monticelli@unige.it

Radiopharmaceuticals: in silico design, diagnostic and therapeutic applications

Teachers: Prof. Elena Cichero, Prof. Francesca Musumeci (UniGe, Dipartimento di Farmacia).

Overview
Nuclear medicine is gaining increasing importance in diagnosis and therapy, with several new radiopharmaceuticals under development, and a few which have recently been approved. This course aims to provide PhD students with essential knowledge of the main radionuclides and radiopharmaceuticals used in the medical field, focusing on their rational and in silico design and their use in therapy and PET and SPECT imaging. The interdisciplinary nature of the field - at the crossroads of (computational) chemistry, physics, and medicine - offers valuable insights into potential research directions and career opportunities for STCM PhD students.

Contents
The course will primarily cover the following topics:
• Introduction to radioactivity, including the basic principles of nuclear decay.
• Radionuclides used in nuclear medicine, focusing on their different applications based on decay modes (alpha, beta, and gamma emission).
• Radiopharmaceuticals:
- Introduction: definition and types of radiopharmaceuticals.
- Design of radiopharmaceuticals via computational methods.
- Synthesis and preparation: methods for radiopharmaceutical preparation using automated synthesizers or cold kits.
- Examples of radiopharmaceuticals for diagnostic, therapeutic, and theranostic applications.
- Targeted delivery mechanisms: the molecular mechanisms underlying the delivery of radiopharmaceuticals to target tissues or organs will be explained with the support of molecular modelling studies.
- Computational methods to optimize radiopharmaceuticals.
• Diagnostic imaging techniques: scintigraphy, single-photon emission computed tomography (SPECT), and positron emission tomography (PET).
• Principles of dosimetry and the biological effects of ionizing radiation.
• Toxicity prediction.

CFU: 2

Indicative period: May-Jun

Contact teacher email: francesca.musumeci@unige.it

Science at large scale facilities: neutron and synchrotron light sources

Teacher: Dr. Alberto Martinelli (CNR-SPIN, SuPerconducting and other INnovative materials and devices institute).

Overview
The course illustrates the use of synchrotron X-ray and neutron radiation (techniques and applications) for the determination of materials' structures and properties in physics, chemistry and related disciplines such as archaeology, geology and environmental science.

Contents
- Introduction to synchrotron radiation.
- fundamentals of the interaction of X-ray with matter.
- Introduction to neutron scattering.
- fundamentals of the interaction of neutrons with matter.
- Matter structure.
- Diffraction Techniques: X-ray diffraction; neutron diffraction and magnetic scattering; pair distribution function.
- Spectroscopic Techniques: XANES and EXAFS.
- Application for beam time: how to write and submit a proposal.

CFU: 2

Indicative period: Feb-Mar-Apr-May-Jun

Contact teacher email: alberto.martinelli@spin.cnr.it

Single crystal diffraction at work

Teacher: Prof. Pavlo Solokha (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
Single crystal X-ray diffraction (SCXRD) is the most important technique to determine the structure of any crystalline material, providing a fundamental basis for all subsequent characterizations aimed at establishing its chemical, physical and functional properties. The aim of this course is to provide the basic principles of SCXRD and guide the students through a typical experiment, from sample selection to crystal structure solution, during practical sessions at the diffractometer.

Contents
- Introduction to single crystal diffraction (crystal systems, space groups, X-ray diffraction theory).
- Overview of instrument hardware and software.
- Techniques for selection and mounting of specimens for X-ray analysis.
- Discussion of data collection techniques and strategies.
- Instruction and practice with APEX4 software package:
  - Structure determination and refinement - use of SHELXTL software package.
  - Preparation of final reports, tables, diagrams and CIF files.
- Visualization of different types of crystal structures.
- Use of Cambridge Crystallographic Database.

CFU: 2

Indicative period: Apr-May-Jun

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The Rietveld method: fundamentals and applications

Teacher: Prof. Cristina Artini (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
The course aims at providing students with the basic knowledge of the Rietveld method for the refinement of powder diffraction data. The method is widely used in the study of the fundamental properties of materials, and it can be of interest for students approaching any crystalline material.

Contents
• Theoretical part:
General introduction on the Rietveld method: historical outline and benefits of the method. Information obtainable from a diffraction spectrum and contributions to the calculated intensity; profile functions. Minimization function and nonlinear least squares method. Refinable parameters and refinement strategies. Correlation among parameters, treatment of data deriving from polyphasic samples; treatment of data containing microstructural information. Agreement factors. Preparation of the input file.
• Hands–on sessions:
Students will individually perform refinements by means of the FullProf software on x–ray diffraction spectra collected by synchrotron radiation or by a laboratory powder diffractometer, with the aim to become familiar with different cases: diffraction spectra of oxides will be supplied, as well as of alloys, of polyphasic samples, of samples showing non negligible microstructural effects.

CFU: 2

Indicative period: Jun-Jul-Sep

Contact teacher email: cristina.artini@unige.it

Water soluble nanoparticles

Teacher: Dr. Teresa Pellegrino (IIT, Nanomaterials for Biomedical Applications).

Overview
An overview of inorganic nanoparticles for biomedical applications: from their nanoscale properties to their synthesis, functionalization, assembly and applications in biomedicine.

Contents
• An introduction to inorganic nanoparticles in biomedical applications: exploiting photoluminescence, magnetic and metallic properties at the nanoscale for accomplish to biomedical needs.
• An overview of water transfer strategies of inorganic nanoparticles: from ligand exchanges and polymer coating protocols to more advances in situ polymer and silica growth approaches.
• Surface functionalization of nanoparticles with biomolecules.
• An overview of characterization techniques suitable for investigating aqueous stabilized nanoparticles.
• Cytotoxicity of nanoparticles: analysis of nanoparticle toxicity as a function of size, shape and composition and methods to evaluate cytotoxicity.
• Degradation of nanoparticles: biological transformations of inorganic nanoparticles into living cells.

CFU: 2

Indicative period: Sep

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TYPE-B COURSES – 2028

Atomic force microscopy, theory and practice

Teacher: Prof. Marco Salerno (UniGe, Dipartimento di Fisica).

Overview
AFM is the major technique of the scanning probe microscopy family. In AFM the interaction force between probe tip and sample is used as a mechanism for detection and local mapping of the sample material properties. The attendees will learn the principles and mechanisms of AFM operation as a force sensor, in the different configurations of static (contact mode) and dynamic interaction (mainly tapping mode). For the latter, precise rules for interpretation of the observables, namely amplitude and phase of cantilever oscillation, will be given. A whole set of practical tips for correct imaging will be provided through examples.

Contents
• Concepts of microscopy: from radiation to physical probe, resolution, reverse use for writing on the materials surfaces.
• Scanning probe microscopy evolution: STM, SNOM; focus on AFM: super-resolved 3D mapping of surface morphology, roughness parameters.
• Basics of digital image processing and analysis.
• Force sensing: tip-sample interactions, Hamaker constant; contact models of Hertz, JKR, DMT. Lateral force microscopy.
• Dynamic AFM: the point mass oscillator model: free and interacting with the sample; virial and dissipation; correlations of amplitude, phase lag, frequency shift and drive change; net attractive and net repulsive regimes, phase contrast.
• Advanced AFM modes for mechanical and electrical characterization of materials: Force spectroscopy and nanoindentation, adhesion and stiffness, scanning Kelvin probe.

CFU: 2

Indicative period: Feb-Mar-Apr

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Catalysts and adsorbents

Teachers: Prof. Elisabetta Finocchio, Prof. Gabriella Garbarino (UniGe, Dipartimento di Ingegneria Civile, Chimica e Ambientale).

Overview
Knowledge of catalytic and adsorption processes, as well as materials properties, is crucial for innovation in industrial and environmental chemistry. To this end, the course will provide students with the fundamentals, properties, and main applications of solid catalysts and sorbents in different fields of technology.

Contents
The course, held in English, describes the main families of catalysts and adsorbents applied in industrial and environmental chemistry and the nature of their behavior. Insight will be provided on materials properties, technologies and molecular interactions, focusing on organo-inorganic composite materials. The course consists of classroom lessons.

CFU: 2

Indicative period: Jan-Feb

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Design of magnetic nano–architecture

Teacher: Dr. Piefrancesco Maltoni, Prof. Davide Peddis, Dr. Sawssen Slimani (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
Within the framework of the PhD program in Sciences and Technologies of Chemistry and Materials, the skills acquired during the course are particularly suitable for PhD students interested in the design and development of materials. Nanostructured magnetic materials will be used as a model system to demonstrate how the design of novel materials relies on the correlation between synthesis, structure, and magnetic properties.

Contents
A physical property depends on the size of an object, if its size is comparable to a dimension relevant to that property. In magnetism typical size – as for example the dimension of magnetic domains or lengths of exchange coupling interaction – are in the nanometer range. For this reason, starting few decades ago, great attention has been directed owards nanostructured magnetic materials where constituent phase or grain structures are modulated on a length scale from 1 to 100 nm. In particular magnetic nanoparticles have generated much interest because of their application in high density data storage, ferrofluid technology, catalysts and biomedical application (drug delivery, contrast enhanced MRI). The course will treat magnetic properties and chemical synthesis methods of magnetic nanomaterials. Then, correlation between synthesis, structure and magnetic properties will be discussed trough several examples[1]–[3].
Basic Course material:
[1] Peddis, D.; Jönsson, P. E.; Laureti, S.; Varvaro, G. Magnetic interactions: a tool to modify the magnetic properties of materials based on nanoparticles, vol. 6., 2014.
[2] Cannas C.; Peddis, D. Design of magnetic spinel oxide nanoarchitetures, La Chimica e l'industria, 2012.
[3] Suber L.; Peddis, D. Approaches to synthesis and characterization of spherical and anisometric metal oxidemagnetic nanomaterials, in Nanomaterials for life science, Wiley., vol. 4, Kumar, C. S. S. R. Ed. Weinheim: Wiley, 2010, p. 431475.

CFU: 2

Indicative period: Jun-Jul

Contact teacher email: davide.peddis@unige.it

Experimental design

Teachers: Prof. Francisco Ardini, Prof. Barbara Benedetti (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
The course gives basic knowledge on the experimental design approach. This multivariate methodology can be applied to the optimization of several processes or more generally to the understanding of a system within an experimental domain; whatever the purpose, this approach is fundamental in every scientific field, since it allows maximizing the quality of information while minimizing the experimental effort.

Contents
- Fundamentals of statistics.
- General principles of multivariate optimization strategies.
- Full factorial designs.
- Screening designs.
- Fractional factorial designs.
- Response surface designs (Central Composite, Doehlert, etc.).
- D–Optimal design.
- Basics of experimental designs with qualitative variables and mixture designs.

CFU: 2

Indicative period: Jun-Jul

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Fundamentals of scanning electron microscopy

Teacher: Prof. Paola Riani, Dr. Riccardo Freccero (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
Thanks to the knowledge of the fundamentals of scanning electron microscopy and energy dispersive x-ray spectroscopy, it is possible to investigate the morphology, defects and chemical composition of homogeneous and heterogeneous polymeric and inorganic materials even at the nanometric level.

Contents
- Structural characteristics: electro-optical column, electron guns, electromagnetic lenses, their aberrations.
- Electron beam – sample interaction: elastic and inelastic scattering, Rutherford and Bethe equations, interaction volume, Influence of beam and specimen parameters on the interaction volume.
- Types of signals: back scattered electrons and their properties; secondary electrons and their properties, characteristics X-rays and their properties, absorption and fluorescence.
- Image formation and detectors: Characteristics of detectors; for SE and BSE signals; image formation. Magnification, resolution, picture element size; depth of field; the roles of the specimen and detector in contrast formation, compositional and topographical contrast.
- EDX spectroscopy: qualitative and quantitative analysis.
- Quick reference to electron backscattering diffraction (EBSD).

CFU: 2

Indicative period: Mar-Apr-May-Sep

Contact teacher email: paola.riani@unige.it

Fundamentals of spectral imaging

Teachers: Prof. Paolo Oliveri (UniGe, Dipartimento di Farmacia).

Overview
The course will introduce the principles of state-of-the-art spectral imaging techniques, ranging from RGB, to multichannel, to hyperspectral implementations. Attendants will learn the potential of spectral imaging techniques as highly efficient non-destructive and non-invasive analytical techniques, understanding which type of instrumental setup is suitable/ideal for different experimental scenarios. Moreover, the course will teach how to extract relevant chemical information and get chemical maps from complex imaging data, with the aid of a freeware application that will be distributed to the attendants.

Contents
• Image analysis and chemical imaging: basic concepts and definitions.
• Point-scan, line-scan, and plane-scan imaging instrumentation.
• Micro- and macro- implementations.
• Integration of the main spectroscopic techniques (UV-Vis, fluorescence, NIR, MIR, Raman, XRF, MS) in imaging systems.
• Main strategies for data mining and processing: pixel-based, object-based, and image-based.
• Extraction of relevant chemical information by means of multivariate methods.
• Principal component analysis (PCA) integrated with interactive brushing approaches.
• Multivariate chemical maps.
• Practical demonstrations through a freeware application (PoliBrush).
• Applications in several fields (biomedical, environmental, cultural heritage, forensic sciences, food sciences).

CFU: 2

Indicative period: Apr-May

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Innovative pharmaceutical dosage forms: preparation and control methods

Teachers: Prof. Giorgia Ailuno, Prof. Sara Baldassari, Prof. Eleonora Russo, Prof. Guendalina Zuccari (UniGe, Dipartimento di Farmacia).

Overview
The development of innovative pharmaceutical dosage forms aims to enhance therapeutic efficacy, bioavailability, and patient compliance. Key advancements include controlled drug release, mucoadhesive systems, and nanotechnology-based carriers. Preformulation studies focus on characterizing the solid-state properties of drugs for optimal formulation. Mucoadhesive systems use bioadhesive polymers to improve drug retention. Nanoparticles enable sustained release, while solubilizing agents like cyclodextrins enhance poorly soluble drugs. These innovations optimize drug delivery and therapeutic outcomes.

Contents
Some theoretical and practical aspects of the development of drug release systems will be described. Preformulation: theoretical aspects relative to characterization of the solid state of drugs, devoted to rational development of dosage forms. Mucoadhesive dosage forms: preparation methods, determination of adhesiveness, excipients used, with particular attention to adhesive polymers, also in relation to systems based on nano and microparticles. Nanoparticle and micellar systems based on polymeric carriers for sustained drug release. Cyclodextrins and poloxamers as solubilizing agents for poorly soluble drugs.

CFU: 2

Indicative period: May

Contact teacher email: eleonora.russo@unige.it

Instrumental techniques for trace elements determination in pharmaceuticals, inorganic nanomaterials, food products, environmental samples, and *in vivo* biokinetics evaluation

Teacher: Prof. Giuliana Drava (UniGe, Dipartimento di Farmacia), Prof. Valerio Voliani (UniGe, Dipartimento di Farmacia).

Overview
The main instrumental analytical techniques for trace element determination in complex matrices are presented, with a focus on atomic spectrometry and on the elements of interest for living organisms. The assessment of analytical result accuracy is illustrated. The application of statistical techniques of experimental design and multivariate analysis is shown using a set of case studies. A focus on the application of atomic spectrometry for in vivo biokinetics evaluation of inorganic nanomaterials is presented. This course is pivotal for STCM students interested in the determination of trace elements in pharmaceuticals, environment and for nano/bio-interactions analysis.

Contents
- Sampling and sample preparation for analytical determination.
- Trace element determination in complex matrices.
- Matrix effects, interferences study and calibration methods.
- Assessment of analytical result accuracy.
- Application of statistical techniques of experimental design and multivariate analysis.
- Real case discussion in pharmaceuticals, food products, environmental samples and nanotoxicology.

CFU: 2

Indicative period: Mar-Apr-May

Contact teacher email: giuliana.drava@unige.it

Introduction to functional ceramic materials. Structure, properties, preparation and applications

Teacher: Dr. Vincenzo Buscaglia (ICMATE–CNR, Istituto di Chimica della Materia Condensata e di Tecnologie per l'Energia).

Overview

The aim of the course is to provide an overview of the main types of functional ceramic materials and their commercial applications. The lessons will be mainly focused on dielectric, piezoelectric and ferroelectric oxides, ionic and mixed conductors with main focus on composition-structure-property relationships and special attention to the impact of microstructure on properties. Processing and large-scale applications will be discussed.

Contents

The specific and sometimes unique magnetic, electrical and optical properties of ceramic materials have promoted their broad application in many electronic and optoelectronic devices. Typical examples include barium titanate ($BaTiO_3$) as a dielectric material with high dielectric constant for multilayer ceramic capacitors, lead zirconate titanate ($Pb(Zr,Ti)O_3$) as fundamental component of piezoelectric actuators and transducers, lithium niobate ($LiNbO_3$) for its use in optoelectronic devices and yttrium-doped zirconia ($Y:ZrO_2$) as solid electrolyte in solid-oxide fuel cells (SOFCs). The aim of the course is to provide an overview of the main types of functional ceramic materials and their commercial applications. For each specific class of material a representative compound will be selected and the corresponding composition-microstructure-property relationships will be illustrated and discussed. Typical examples of most common applications and case histories about the optimization of materials and devices in terms of processing and performances will be provided.

In more detail:

- Processing of ceramics: generalities, forming and sintering.
- Effect of grain boundaries on electrical properties.
- Ceramics for electronics: dielectric, ferroelectric and piezoelectric ceramics, related commercial applications.
- Miniaturization of devices and related issues.
- Ceramics for energy (SOFCs).
- Gas separation membranes.

CFU: 2

Indicative period: May

Contact teacher email: vincenzo.buscaglia@cnr.it

Introduction to polymer physical chemistry and characterisation techniques

Teacher: Prof. Nicola Tirelli (IIT, Polymers and biomaterials).

Overview
This short course provides a very basic understanding of why macromolecules must not be seen as 'molecules, just bigger'. Actually, polymers are not molecules. They are statistical ensembles of molecules that differ in size and in basically any physical property, i.e. they are distributions of very diverse objects, which we are unable to separate. As a result, polymers can only be comprehended in statistical terms, and their thermodynamics is much more skewed towards entropy than that of 'small' molecules. In this course, we will introduce the basic concepts of polymer physical chemistry and discuss a few cases of its use in the characterization of these macromolecules.

Contents
• The molecular weight distribution of macromolecules vs. the single molecular weight of small molecules. The key features of a statistical approach as opposed to the more usual, deterministic thermodynamics. What molecular weight distribution entails in terms of physical properties.
• Seeing macromolecules in 3D: random walk and freely jointed chains, more realistic (rigid chains) in unperturbed conditions and in solution. Why longer polymers are not necessarily bigger. Concept of excluded volume
• Characterization techniques, with a specific emphasis on viscosimetry and size exclusion chromatography (SEC, also known as Gel Permeation Chromatography, GPC). Differences between the entropy-based SEC/GPC and all the other (enthalpy-based) chromatographic techniques.
• Wrap-up and assessment.

CFU: 2

Indicative period: Jan

Contact teacher email: nicola.tirelli@iit.it

Main plants used in phytocosmetics and their constituents

Teacher: Prof. Angela Bisio (UniGe, Dipartimento di Farmacia).

Overview
The course aims to provide a comprehensive understanding of the main plants used in phytocosmetics and their bioactive secondary metabolites. Learners will explore the herbal value chain, emphasizing quality assurance and European harmonization efforts. Practical applications of herbs in cosmetic products, including skin and hair care, essential oils, cosmeceuticals, nutricosmetics, and neurocosmetics, will be examined. Finally, the course will provide insights into the formulation and evaluation of herbal cosmetics.

Contents
The main plants (tallophytes and cormophytes) used in phytocosmetics are described, with a focus on their bioactive secondary metabolites.
• Introduction: Common myths and misconceptions; Decorative cosmetics and care cosmetics; Herbal cosmetics; Brief historical outline.
• Herbal market and herbal products: From planting to product: the herbal value chain; Some hints about quality assurance of medicinal and aromatic plants; European harmonization efforts for the quality of medicinal and aromatic plants.
• The protective chemistry of plants: Secondary metabolites; Processes and Products from aromatic plants; Potential of plant cells in culture for cosmetic application; Molecular bio-liquefaction: safety and effectiveness of enzyme bio-catalysis.
• Applications of herbs in cosmetic products: Plants for skin with notes on the plants used in diseases of the skin; Plants for hair; Use of essential oils; Cosmeceuticals; Nutricosmetics; Neurocosmetics.
• Formulation and evaluation: Herbal cosmetics; Novel approaches.

CFU: 2

Indicative period: Jan-Feb

Contact teacher email: angela.bisio@unige.it

New trends in organic synthesis

Teachers: Dr. Chiara Lambruschini, Prof. Lisa Moni (UniGe, Dipartimento di Chimica e Chimica Industriale).

Overview
Organic synthesis is advancing rapidly, driven by the continuous discovery of novel reactivities aimed at enabling the efficient construction of complex molecular architectures through step-economical strategies. In this context, multicatalytic bi- and multicomponent reactions will be presented as innovative approaches to achieve molecular complexity in a straightforward manner. The course integrates traditional lectures with active learning methodologies, including flipped classroom sessions, jigsaw activities, and problem-solving exercises.

Contents
- Ideal synthesis and multicomponent reactions (2 h).
- Multicomponent metal/metal catalytic reactions (3 h).
- Multicomponent metal/organo and organo/organo catalytic reactions (3 h).
- Ternary catalysis in bicomponent reactions (trimetal catalysis, 3 h).
- Ternary catalysis in bicomponent reactions (bimetal/organo and biorgano/metal catalysis, 3 h).

The course will include two task assignments, each involving the preparation of a short presentation on selected metal-catalyzed and organocatalytic reactions. Moreover, students will engage in a series of problem-solving sessions designed to apply and consolidate the theoretical concepts acquired through lectures and assigned tasks.

CFU: 2

Indicative period: Jan-Feb

Contact teacher email: lisa.moni@unige.it

Optical properties of materials

Teachers: Dr. Francesco Bisio (SPIN-CNR, Superconducting and other innovative materials and devices institute), Prof. Maurizio Canepa (UniGe, Dipartimento di Fisica), Dr. Michele Magnozzi (UniGe, Dipartimento di Fisica).

Overview
This is a course on the optical properties of materials and nanomaterials, the spectroscopic experimental methods to study them, and their applications in the field of photonics. Students will acquire up-to-date knowledge concerning the optical properties of composite nano-materials of interest in the field of photonics. Knowledge of electromagnetism and waves, at the level of general physics courses, and basic knowledge of quantum mechanics are required. Basic knowledge of optics and elementary notions of solid-state physics are useful.

Contents
The course aims to provide a comprehensive and up-to-date introduction to the interaction processes of light with various classes of materials, with reference to the latest scientific and technological applications of photonics, including quantum technologies and materials for the ecological transition. Optical methods applied to study nanomaterials, such as ultrathin functional films, nanoparticles, quantum dots, new two-dimensional semiconductor materials and nanocomposites, will be discussed.
Non-exhaustive list of topics:
• Dielectric function of materials.
• Optical properties of semiconductors.
• Nanostructures and plasmonics.
• Optical thin films and multilayers.
• Optical and vibrational spectroscopies.

CFU: 2

Indicative period: Apr

Contact teacher email: maurizio.canepa@unige.it

Python programming tools for research in chemistry and materials science

Teacher: Prof. Giulia Rossi, Dr. Andrea Tagliabue (UniGe, Dipartimento di Fisica).

Overview
This course provides PhD students with the fundamentals of scientific programming using Python, with a focus on applications relevant to research in chemistry and materials science. Students will learn how to manipulate data, automate tasks, and visualize results, gaining essential skills for handling experimental data. The course is designed to be accessible and practice-oriented. The course is suitable for students from all curricula of the PhD program, including those with no prior coding experience.

Contents
The course combines lectures and hands-on exercises. It begins with an introduction to programming logic and Python syntax, followed by control structures, functions, and basic data structures. Students will learn to handle chemical and materials-related data through examples involving file parsing, batch processing, and numerical calculations. The course introduces widely used Python libraries such as NumPy and Matplotlib, which are employed to analyze and plot data. Emphasis is placed on practical problems faced in laboratory work. One session is devoted to automating repetitive tasks and managing data files, and the course concludes with a mini-project where students implement a small script tailored to analyze their own data.

CFU: 2

Indicative period: May-Jun

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Surface science

Teacher: Prof. Luca Vattuone (UniGe, Dipartimento di Fisica).

Overview
At the end of the course, the student will be able to: (a) read specialized papers in fundamental Surface Science and in Surface Chemistry; (b) identify the most common surface structures and reconstructions; (c) indicate the most widely used experimental techniques for the deterination of fundamental surface science properties; (d) identify the main surface phenomena occurring during a catalytic reaction.

Contents
• Surface structure. Structure of bare surfaces. Adsorbate induced reconstruction of surfaces.
• Solid band structure and its modification in presence of interfaces.
• Phonon vibrations.
• Experimental techniques applied to surface analysis.
Scanning tunneling Microscopy and spectroscopy. Low Energy Elecron Diffraction. Electronic and vibrational spectroscopy. Microcalorimetry on single crystals.
• Gas surface interaction: physisorption and chemisorption dynamics. Physisorption. Non dissociative chemisorption. Dissociative chemisorption. Influence of translational and internal degrees of freedoms of gas phase molecules on their sticking probability at surfaces. Experimental study of sticking probability and of simple reactions by molecular beams. Langmuir Hinshelwood and Eley – Rideal reaction mechanisms.

CFU: 3

Indicative period: Apr-May-Jun

Contact teacher email: luca.vattuone@unige.it

TYPE-C COURSES – 2027 and 2028

Introduction to transmission electron microscopy for materials science

Teachers: Dr. Rosaria Brescia (IIT, Electron Microscopy), Dr. Giorgio Divitini (IIT, Electron Spectroscopy and Nanoscopy)

Overview
This course aims to provide basic concepts and some laboratory examples in electron microscopy (EM), precious both for the use of basic techniques and for a correct interpretation of outputs of EM-based investigations. The course will focus mainly on transmission EM (TEM), in particular applied in the area of materials science. The main concepts in EM will be provided, starting from electron sources, electron optics and electron-specimen interactions. The main signals and operation modes of interest in (scanning) TEM will be treated, together with analytical EM techniques.

Contents
• Main concepts in electron microscopy (EM):
- electron sources.
- electron optics.
- electron-specimen interactions.
• Main operation modes in (scanning) transmission EM (TEM/STEM):
- bright field TEM.
- electron diffraction.
- dark field TEM.
- high-angle annular dark field STEM.
• Analytical EM:
- energy-dispersive X-ray spectroscopy (EDS).
- electron energy-loss spectroscopy (EELS).

CFU: 1

Indicative period: Apr-May

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Materials characterization 1

Teachers: Dr. Luca Ceseracciu, Dr. Silvia Dante, Dr. Matteo Lorenzoni, Dr. Lea Pasquale, (IIT, Materials Characterization).

Overview
The course offers theoretical and practical foundations in key techniques for structural and morphological analysis of materials. Students will learn to select the most suitable method based on material type and desired information, and to interpret experimental data in relation to material properties. Understanding these properties is essential for both research and industry. The techniques covered—crucial in materials science, solid-state physics, engineering, and nanotechnology—equip students with the skills to critically analyze and contribute to the development and optimization of advanced materials.

Contents
An overview of different characterization techniques will be given, through a combination of theory classes and examples in the laboratory. In particular, the course will deal with (a) X-ray based techniques: The theoretical basis as well as the practical application of X-ray Diffraction (XRD) will be presented. The course will also include lectures on X-ray techniques for the characterization of non-crystalline or partially ordered materials (small-angle scattering, SAXS); (b) Mechanical Characterizations: The course will cover the basic theory of deformation of different classes of materials and their relationship with microstructure. The most common mechanical characterization techniques will be presented, with a special focus on uniaxial tension tests; (c) Atomic Force Microscopy (AFM): The lecture will present the basic principles underlying AFM operation, and will shortly comment on the meaning of roughness for 3D surface images obtained by whatever imaging technique. Examples of the different physical quantities that can be probed (e.g. stiffness, friction, electrical potential, surface current) will be shown.

CFU: 1

Indicative period: Mar-Apr-May

Contact teacher email: mirko.prato@iit.it

Materials characterization 2

Teachers: Dr. Silvia Dante, Dr. Luca Goldoni, Dr. Lea Pasquale, Dr. Mirko Prato (IIT, Materials Characterization).

Overview
The course provides a foundation in key spectroscopic techniques (XPS, NMR, Raman, XRF) for qualitative and quantitative chemical analysis of materials. Students will learn to interpret spectra, extract structural and chemical information, and choose the most suitable technique based on material type and scale. These methods are essential for understanding composition and electronic structure, with applications in materials science, engineering, energy, environment, and life sciences. The course equips students with the skills needed to address complex characterization challenges in both academic and industrial settings.

Contents
An overview of different characterization techniques will be given, through a combination of theory classes and examples in the laboratory. In particular, the course will deal with (a) X-ray based techniques: The theoretical basis as well as the practical application of X-ray Photoelectron Spectroscopy (XPS) for the study of the surface chemistry of materials will be presented, along with micro-X-ray fluorescence (μ-XRF) for the examination of the elemental composition of a wide variety of sample types. (b) Nuclear Magnetic Resonance: The course will cover the basic theory of NMR for structure elucidation, as well as some notions for studying the dynamic of molecules in solution; (c) Raman: The lecture will present the basic principles underlying Raman data acquisition and interpretation, to provide a structural fingerprint by which molecules can be identified.

CFU: 1

Indicative period: Mar-Apr-May

Contact teacher email: mirko.prato@iit.it

Nanomaterials and nano heterostructures: colloidal synthesis and chemical transformations

Teacher: Dr. Luca De Trizio (IIT, Chemistry Facility).

Overview
Synthesis of colloidal nanocrystals, their surface functionalization and and post-treatment transformations.

Contents
The course aims at outlining the fundamental steps that characterize the colloidal synthesis of nanocrystals. Specifically, it will first address the kinetics and thermodynamics of nanocrystal nucleation and growth, and how these processes can be controlled. Then, the course will explore the surface energy of nanocrystals, which ultimately determines their shape, and how it is influenced by surfactants. It will also address how surfactants stabilize colloidal nanocrystal dispersions and how the ligand shell can be tuned to tailor the nanocrystals' properties. Finally, the course will describe one of the most widely studied post-synthesis strategies employed to finely modify the composition of pre formed colloidal nanocrystals: the cation exchange reaction. This chemical approach enables the replacement of cations in pre-formed nanocrystals with new, desired cations, while preserving the original anion framework. Through this technique, it is possible either to completely alter the composition of colloidal nanocrystals, gaining access to new nanomaterials, or to engineer them via partial cation exchange, resulting in alloyed or heterostructured nanoparticles.

CFU: 1

Indicative period: Jun

Contact teacher email: luca.detrizio@iit.it

Analytical models for magnetic actuation

Teacher: Dr. Edoardo Sinibaldi (IIT).

Overview
The course aims to provide PhD students with basic quantitative tools for the preliminary analysis/design of magnetic systems, with some focus on actuation. The contents are devised for a gamut of profiles (ranging, e.g., from students interested in the design of magnetic tools to those working with magnetic particles), with a basic academic background in classical physics and calculus. Frontal teaching will be mainly based on whiteboard and live interaction with students (a beamer will be nevertheless used for some topics). Besides directly benefiting students keen on modeling, the course will provide experimentalists with basic theoretical notions useful for design and analysis/characterization of lab experiments.

Contents

Concise overview of state-of-the-art magnetic actuation systems for biomedical applications (magnetic steering/manipulation, magnetic targeting/retrieval, etc.). Analytical models for magnetic dipoles (field/gradient, force/torque; force/torque between dipoles). Analytical models for coils (Maxwell/Helmholtz coils, etc.). Additional contents could be defined (also considering the main research scopes of the audience) out of the following topics: illustrative analytical models for magnetic particles in fluid flows; selected analytical models for permanent magnets systems; practical implementation (using a common numerical environment) of dipoles models, aimed to illustrate basic design choices for magnetic actuation.

CFU: 1

Indicative period: Mar-Apr-May

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