BIOPHAM Master - Syllabus of the courses proposed in
Track 2: Biomaterials for pharmaceutical applications (UNIPI-USK-UNIPI)

TERM 1 – University of Pisa (UNIPI) – Italy

Course name	Classification	ECTS	Hours face-to-face in class	Compulsory/optional Recommendation
Quantum physics of matter	Physcs	6	48	Compulsory for students with no strong "quantum mechanics" background
Solid state physics	Physics	6	48	compulsory for students with no strong "quantum mechanics" background
Disordered and off-equilibrium systems	Physics	6	48	Compulsory
Polymer science and engineering	Materials Science	6	48	Optional (6 ECTS must be chosen in this group)
Transport phenomena in materials	Materials Science	6	48	
Mechanical Behaviour of Materials	Materials Science	6	48	
Biofluids and Materials interactions	Materials Science	3	30	Compulsory
Computational materials science	Materials Science	6	48	Optional (6 ECTS must be chosen in this group);recommended for students with strong interest into scientific computation
Bioinformatics	Computer Science	6	48	Optional (6 ECTS must be chosen in this group); recommended for students with weak background in computing
English for scientific writing and communication	Soft Skills/Language knowledge	3	30	Compulsory
TOTAL		**30**	**252**	

<table>
<tr><th colspan="4">TERM 1 – University of Pisa (UNIPI) – Italy</th></tr>
<tr><td>Course name</td><td colspan="3">QUANTUM PHYSICS OF MATTER</td></tr>
<tr><td>Credit Points (ECTS) 6</td><td>Hours (Face-to Face in class):
Lectures:48
Practical works: 0
Total: 48</td><td>Duration
1 semester</td><td>Mode
Compulsory for students with no strong “quantum mechanics” background</td></tr>
<tr><td>Instructors</td><td colspan="3">Giuseppe Carlo La Rocca</td></tr>
<tr><td>Contents</td><td colspan="3">Introduction to quantum mechanics:
Waves and particles. Wave-particle duality and uncertainty principle. Wave function. Schroedinger equation and stationary states. Expectation values.
Atomic Physics:
First atomic models and their shortcomings. Hydrogen atom: energy spectrum, angular momentum and eigenfunctions. Electron spin. Pauli exclusion principle. Helium atom, singlet and triplet states. Many-electron atoms, periodic system of elements. Atomic spectroscopy.
Molecular physics:
Adiabatic approximation. The ionized hydrogen molecule. The hydrogen molecule. Homonuclear and heteronuclear diatomic molecules.Polyatomic molecules. Molecular vibrations. Molecular Spectroscopy.
Condensed matter physics:
Structure of liquids, amorphous solids and crystals. X-ray diffraction. Types of crystals: molecular, ionic, covalent and metallic. Boltzmann distribution, equipartition of energy. Quantum statistics: bosons and fermions. Phonons and specific heat of solids. Free electron model of metals: electrical conductivity and specific heat.</td></tr>
<tr><td>Skills acquired</td><td colspan="3">On successful completion of the course students will be familiar with the basic concepts and methods of nonrelativistic quantum mechanics which are at the base of the modern theory of atoms, molecules and condensed matter systems. He/she will also be able to peruse the literature on the quantum microscopic theory of matter that might be useful for his/her studies/research/work.</td></tr>
<tr><td>Examination</td><td colspan="3">Oral exam</td></tr>
<tr><td>Classification</td><td colspan="3">Physics</td></tr>
</table>

BIOPHAM Master - Syllabus of the courses proposed in
Track 2: Biomaterials for pharmaceutical applications (UNIPI-USK-UNIPI)

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Solid State Physics**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures:48 Practical works: 0 Total: 48	Duration 1 semester	Mode Compulsory for students with strong "quantum mechanics" background
Instructors	Stefano Roddaro		
Contents	Electrons in a one-dimensional periodic potential. Electron tunneling through a periodic potential. Velocity, quasimomentum and effective mass of an electron in a band. Geometric description of crystals: direct and reciprocal lattices. Von Laue and Bragg scattering. The Drude electron gas. The theory of Sommerfeld. Energy and density of states of a two-and three-dimensional electron gas in a magnetic field. De Haas van Alphen effect. Landau diamagnetism and Pauli paramagnetism. Theory of harmonic crystal. Phonons. Optical properties of semiconductors and insulators. Charge transport in intrinsic and doped semiconductors. Fermi level in intrinsic semiconductors. Law of mass action. Donor and acceptor levels. Fermi level in doped semiconductors..		
Skills acquired	On successful completion of the course students will be able to interpret the main experimental phenomenology of condensed matter - will obtain a sound knowledge of structural, electronic, optical and vibrational properties of solids..		
Examination	Oral exam		
Classification	Physics		

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Disordered and off-equilibrium systems**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures:44 Practical works: 4 Total: 48	Duration 1 semester	Mode Compulsory
Instructors	Simone Capaccioli		
Contents	***1. From order to disorder*** Non-periodical Long range positional order: quasi-crystals. Disorder in long range positional atomic systems (cellular disorder): Substitutional disorder:		

	interstitial and substitutional impurities, vacancies; Orientational disorder: plastic crystals (e.g. fullerene). Disorder in atomic systems without long range positional order (topological disorder): Base elements in real crystals: Dislocations and Burger's vector, Interfacial defects. Liquid state and amorphous state: N-bodies distribution functions, particular case: pair distribution; static structure factor; Hard sphere atomic liquids: Percus-Yevick theory. ***2. From equilibrium to out of equilibrium*** Supercooled metastable states and glass transition in liquids: Van Hove function and its momenta; Collective and microscopic dynamics: cage effect and vibrational properties, local and structural relaxation, relaxation time distribution, diffusion. Rheology and visco-elasticity. Simple models of glass transition: Free volume, Configurational entropy. Elements of non-equilibrium thermodynamics: Zero Principle: fictive temperature in glasses, fluctuation-dissipation theorem violation. ***3. Experimental techniques: structure and dynamics of disordered systems*** Scattering from disordered systems: generalities: Scattering cross sections, coherent and incoherent scattering; Static and dynamic structure factor, elastic and inelastic scattering; Spatial, temporal and spatio-temporal correlation function. Structure of disordered systems: X-ray diffraction at wide and small angle; Dynamics in disordered systems: inelastic X-ray scattering, photocorrelation spectroscopy. Neutron scattering: neutron diffraction at wide and small angle. Comparison with X-ray; inelastic neutron scattering and spectroscopy
Skills acquired	On successful completion of the course students will be able to understand and analyse scientific reports concerning experimental, theoretical and computational studies concerning the physics of disordered and off-equilibrium systems.
Examination	Knowledge will be assessed via: ongoing assignments and final oral exam; the oral exam can be replaced by a seminar given at the joint winter school.
Classification	Physics

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Polymer Science and Engineering**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures:48 Practical works:0 Total: 48	Duration: 1 semester	Mode: Optional (6 ECTS must be chosen in the group of Materials Science list)
Instructors	Giuseppe Gallone		

Contents	Basic review of general concepts in polymer science. Generalities of step-growth polymerization and of chain-growth polymerizations. Thermodynamics of ideal solutions. Characterization of polymers at molecular level. Measurement of frictional properties of polymers in solutions. Molar mass distribution. Spectroscopic methods for characterization of chemical composition and molecular microstructure of polymers. The amorphous state of polymers. The crystalline state in polymers. Melting of crystalline polymers. Elasticity of rubbers. Electrical properties of polymers. Processing of polymers.
Skills acquired	The student who successfully completes the course: - will be aware of the specific characteristics of the materials included into the class of polymers, particularly with respect to structure and properties; - will acquire knowledge of both mechanisms for synthesizing polymeric materials and relevant industrial production and processing technologies; - will acquire basic knowledge of the principal experimental techniques for characterizing physical-chemical properties of polymeric materials
Examination	Oral Exam
Classification	Materials Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Transport Phenomena in Materials**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures:40 Practical works:8 Total: 48	Duration: 1 semester	Mode: Optional (6 ECTS must be chosen in the group of Materials Science list)
Instructors	Marco Lagnoni		
Contents	INTRODUCTION. Local equilibrium, definition of convective and diffusive fluxes, materials transport properties, dimensionless numbers (Reynolds, Prandtl, Schmidt, Peclet, etc), origin of diffusive equations & random walk. MICROSCOPIC GOVERNING EQUATIONS. Derivation of microscopic balance equations (general, mass, species, internal energy, momentum), Eulerian and Lagrangian approaches, tensor notation and operators. STATIONARY HEAT CONDUCTION. Governing equation and boundary conditions, Newton law of cooling, Biot and Nusselt numbers, unidirectional heat conduction (linear, cylindrical and spherical coordinates), effective thermal conductive of composite materials, heat conduction with heat source. TIME-DEPENDENT HEAT CONDUCTION. Step response in a semi-infinite slab, self-similar solutions,		

	response to heat pulse. FUNDAMENTALS OF MATERIAL TRANSPORT. Species fluxes and velocities, convection vs diffusion, mass vs molar basis, constitutive equations of diffusion (Fick law), balance equations and boundary conditions. STATIONARY MATERIAL TRANSPORT. Diffusion in a stagnant film, effective mass transport coefficient, Sherwood number, simplifications in the dilute limit, diffusion with heterogeneous reaction, diffusion with homogeneous reaction, Thiele modulus and effectiveness factor, scaling of regimes (kinetic, internal and external). TIME-DEPENDENT MATERIAL TRANSPORT. Unidirectional diffusion in semi-infinite slab with Robin-type boundary condition (Crank's solution). MOMENTUM TRANSPORT. Laminar and turbulent flows, velocity profiles in a pipe, non-Newtonian fluids, flow in porous media, Knudsen effects. TUTORIALS. Use of Microsoft Excel and codes in Comsol Multiphysics: basic use of the codes, isotope exchange.
Skills acquired	At the end of the class the student: • will have a deep knowledge of the fundamentals to transport phenomena (species, heat and momentum) according to a unified chemical engineering perspective • will be able to use quantitative balances (steady-state and dynamic) and to set up simple models, with or without analytical solution • will have a general understanding enabling her/him to apply the theory to more advanced applications • will have got some practical experience on numerical simulation of transport phenomena with commercial codes
Examination	During the final oral exam, the level of knowledge will be assessed through quantitative exercises to be set and solved by the candidate.
Classification	Materials Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Mechanical Behaviour of Materials**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures:40 Practical works:8 Total: 48	Duration: 1 semester	Mode: Optional (6 ECTS must be chosen in the group of Materials Science list)
Instructors	Andrea Lazzeri		
Contents	1. Introduction to deformation behaviour: Concept of stresses and strains, engineering stresses and strains, Different types of loading and temperature encountered in applications. 2. Tensile Test - stress-strain response for metal, ceramic and polymer, elastic region, yield point, plastic deformation, necking and fracture.		

	3. Bonding and Material Behaviour, theoretical estimates of yield strength in metals and ceramics. 4. Elasticity (the State of Stress and strain, stress and strain tensor, tensor transformation, principal stress and strain, elastic stress-strain relation, anisotropy, elastic behaviour of metals, ceramics and polymers). 5. Viscoelasticity (Molecular foundations of polymer viscoelasticity. Rouse-Bueche theory, Boltzmann superposition principle, mechanical models, distribution of relaxation and retardation times, interrelationships between mechanical spectra, the glass transition, secondary relaxations, dielectric relaxations. 6. Plasticity (Hydrostatic and Deviatoric stress, Octahedral stress, yield criteria and yield surface, texture and distortion of yield surface, Limitation of engineering strain at large deformation, true stress and true strain, effective stress, effective strain, flow rules, strain hardening, Ramberg-Osgood equation, stress -strain relation in plasticity, plastic deformation of metals and polymers). 7. Microscopic view of plastic deformation: crystals and defects, classification of defects, thermodynamics of defects, geometry of dislocations, slip and glide, dislocation generation - Frank Read and grain boundary sources, stress and strain field around dislocations, force on dislocation - self-stress, dislocation interactions, partial dislocations, twinning, dislocation movement and strain rate, deformation behavior of single crystal, critical resolved shear stress (CRSS), deformation of poly-crystals, Hall-Petch and other hardening mechanisms, grain size effect - source limited plasticity, Hall-Petch breakdown, dislocations in ceramics and glasses. Effects of microstructure on the mechanics of polymeric media: deformation modes, yield, rubber toughening, alloys and blends. 8. Fracture mechanics (energetics of fracture growth, plasticity at the fracture tip, measurement of fracture toughness, - Linear fracture mechanics -KIC. Elasto-plastic fracture mechanics - JIC, Measurement and ASTM standards, Design based on fracture mechanics, effect of environment, effect of microstructure on KIC and JIC. Application of fracture mechanics in the design of metals, ceramics, polymers and composites, damage tolerance design, elements of fractography) 9. Fatigue (S-N curves, low- and high-cycle fatigue, laboratory testing in fatigue, residual stress, surface and environmental effects, fatigue of cracked components, designing out fatigue failure, Life cycle prediction, Fatigue in metals, ceramics, polymers and composites. 10. Creep. Creep in crystalline materials (stress-strain-time relationship, creep testing, different stages of creep, creep mechanisms and creep mechanism maps, diffusion, creep and stress rupture, creep under multi-axial loading, microstructural aspects of creep and design of creep resistant alloys, high temperature deformation of ceramics and polymers.
Skills acquired	After the completion of the course, the students will be able to: understand the mechanism of plastic deformation and origin of materials strength; suggest ways by which engineering materials may be intrinsically strengthened; derive ductile-brittle transition temperature and select materials accordingly; understand high temperature mechanical behavior of materials and be able to select the materials for high temperature applications; design and select

	engineering components based on the principles of fracture mechanics and fatigue; improve materials resistance to fracture and fatigue performance.
Examination	Oral Exam
Classification	Materials Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Biofluids and Materials Interaction**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 24 Practical works: 6 Total: 30	Duration: 12 weeks	Mode: Compulsory (Tracks 2 and 3)
Instructors	Serena Danti		
Contents	**1. Body Fluids and Biofluids** Fundamentals of fluids (Newtonian and non-Newtonian behavior, viscosity, density, surface tension). Overview of biofluids: intracellular and interstitial fluids, blood composition and rheology, plasma and cellular components, lymph, urine, cerebrospinal and other extracellular fluids, saliva, and gastrointestinal fluids. Artificial and simulated body fluids; cell culture media composition and functions. **2. Transport and Diffusion Phenomena** Flow and pressure in the human circulatory system (Hagen–Poiseuille law, shear-rate dependence, Fåhræus–Lindqvist effect). Osmosis, diffusion, and filtration across membranes; hypertonic, hypotonic, and isotonic conditions. Oncotic and hydrostatic pressures; Starling equation; renal filtration and glomerular transport mechanisms. **3. Biofluid–Material Interactions** Surface and interfacial phenomena: wettability, contact angle, capillary effects, biofouling, and biomimetic (Lotus effect) surfaces. Strategies for tuning surface hydrophilicity/hydrophobicity (chemical and physical modifications). Hemocompatibility: Vroman effect, protein adsorption, thrombosis cascade, and design of blood-contacting materials. Dialysis membranes: structure, fabrication (phase inversion), classification (RO, nano-, ultra-, microfiltration), and operation principles (diffusion and convection). Biomaterials for vascular grafts, prostheses, and biotextiles. Degradation of biomaterials: mechanisms of hydrolysis and enzymatic attack; bulk vs. surface erosion; corrosion and metal degradation in vivo. Absorbent materials: fluid–material interaction (Jurin's and Washburn equations), superabsorbent polymers (SAPs), swelling behavior, osmotic response, and applications in hygiene and biomedical products.		

	Smart biomaterials: pH-responsive hydrogels (e.g., gellan gum, chitosan) for targeted drug delivery. **4. Biofluids for Diagnostics and Organ-on-Chip Systems** Protein electrophoresis and ELISA principles; colorimetric and fluorescence detection; clinical diagnostic applications. Introduction to microfluidics: laminar flow, diffusion, capillary effects, and surface energy at the microscale. Wettability and material design for microfluidic systems. Concepts and challenges of organs-on-a-chip: bioinspired and biomimetic approaches.
Skills acquired	On successful completion of the course, the students will acquire knowledge of biofluid composition, transport phenomena in the human body, and biomaterial interface chemistry; develop skills to design, characterize, and evaluate biomaterials and diagnostic systems interacting with biological fluids; and demonstrate attitudes/competences in applying critical thinking, ethical awareness, and interdisciplinary reasoning to biomedical and pharmaceutical challenges.
Examination	ORAL exam, laboratory reports Final Exam: 50% Laboratory reports 50%
Classification	Materials Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Computational Materials Science**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures:48 Practical works:0 Total: 48	Duration: 1 semester	Mode: Optional (6 ECTS must be chosen in the computing group); recommended for students with strong interest into scientific computation
Instructors	Giuseppe Brancato		
Contents	Intermolecular Forces: Hydrogen bonding, Electrostatic interactions, London forces. Molecular clusters, Supramolecular assemblies. Thermodynamics: Variational formulation. Free energy of a reaction, Equilibrium constants. Statistical Mechanics: Gibbs ensemble, Mechanical system, Generalized		

	coordinates, Lagrangian formalism. Hamiltonian formalism, Hamilton's equation, Phase space. Properties of Hamiltonian systems, Conservation laws, Canonical transformation, Poisson brackets, Liouville's operator, Equation of motion of a dynamical variables. Liouville's equation and theorem, Probability density, Microcanonical ensemble, Canonical ensemble. Molecular Dynamics: Definition, Foundations of molecular simulations, Limits and approximations. Overview of the basic ingredients (Energy potential, Force fields, Numerical integrators). Energy potential, Force fields, Numerical integrators. Force field terms (bonding, bending, torsion, non-covalent interactions). Molecular Dynamics: Coordinate and Velocity inizialitation, Integrators. Numerial integrators (velocity Verlet, Leapfrog), Statstical mechanichal ensemble, Thermal and pressure coupling. Enhanced Sampling Methods. Simulation of the Kv ion channel. Simulation of a lipid bilayer. Fundamentals of enhanced sampling techniques. Implicit solvent and continuum electrostatic modeling. From collisional theory to stochastic dynamical systems. Stochastic differential equations and Statistical Mechanics. Structural properties: distribution functions, radial distribution functions. Monte Carlo methods: Numerical Integration, Importance samplig. Free Energy methods. Free Energy Methods: Thermodynamic Integration, Free energy perturbation, Umbrella Sampling Free Energy Methods: Metadynamics, Jarzinski method, Adiabatic free energy.
Skills acquired	On successful completion of the course students will be able to: - comprehend molecular modeling techniques currently used in the field of life and material sciences - develop competences on some of the most common computational methodologies used in molecular sciences - develop computational skills through tutorials and exercises
Examination	Oral Exam. In addition to questions related to the basic knowledge of the course, students will be asked to present a scientific problem of their interest suitable to be treated with molecular modelling methodologies
Classification	Materials Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**Bioinformatics**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 37 Practical works: 11 Total: 48	Duration 1 semester	Mode: Mode: Optional (6 ECTS must be chosen in the computing group); recommended for students with weak background in computing

Instructors	Alessio Bechini
Contents	The course aims to provide both conceptual and computational tools for data analysis in molecular biology, using Python, one of the most popular languages in bioinformatics and machine learning. The most prominent topics in bioinformatics are developed in the course: usage of data banks, algorithms for sequence analysis, alignments, creation and analysis of phylogenetic trees.
Skills acquired	Upon completing the module, the student will successfully master the basic concepts in Bioinformatics and will be able to use the Python programming language to deal with related problems.
Examination	Project, and subsequent oral exam
Classification	Computer Science

TERM 1 – University of Pisa (UNIPI) – Italy			
Course name	**English for scientific writing and communication**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 30 Practical works: Total: 30	Duration 1 semester	Mode Compulsory
Instructors	Alessandra Meoni (professor still to be confirmed)		
Contents	Meaning and pronunciation of keywords in Mathematics Specific use of grammar in a scientific paper. Word order and conciseness. Basic information about the structure of a scientific paper “Good Writing Reflects Clear Thinking”: hints and tips to face the possible difficulties in writing a good paper		
Skills acquired	Students will acquire awareness of the basic linguistic skills for writing and publishing scientific articles in English, as well as the presentation skills necessary to ensure an interactive participation in international academic contexts (conferences, seminars, webinars, symposia, etc.). The course also prompts the students to practice their "soft skills" (transversal skills), such as teamwork, cognitive skills-information skills, social skills-interpersonal communication, problem-solving, creativity, mental adaptability, and flexibility. All these skills are necessary for effective iteration in complex organizational contexts, both in the academic community and in future professional spheres.		
Examination	Oral exam and project		

Classification	Soft Skills/Language knowledge

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain				
Course name	**Classification**	**ECTS**	**Hours face-to-face in class**	**Compulsory/optional Recommendation**
Molecular and soft condensed matter	Physics-Chemistry	4	36	Compulsory
Materials science of drugs	Materials Science	4	36	Compulsory
Large facilities: synchrotron and neutron sources	Materials Science	5	45	Compulsory
Biophysical and materials science characterisation	Physics-Chemistry	4	36	Compulsory
Biopham Short Internship	Depends on the project	5	45	Compulsory
Complexity in biological systems	Biophysics	4	36	Optional 2 courses to be chosen out of 3
Stochastic methods for optimization and simulation	Physics	4	36	
Machine learning with neural networks	Physics	4	36	
TOTAL		**30**	**270**	

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain			
Course name	Materials science of drugs		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 30 Practical works: 6 Total: 36	Duration: half semester	Mode Compulsory (Tracks 1 and 2)
Instructors	J. Ll. Tamarit, P. Lloveras, M. Romanini		
Contents	1. Basics concepts of crystallography Translational order, unit cell, Bravais lattices. Point groups, space groups, crystal systems. Crystallographic planes, reciprocal lattice, Miller indices. From crystal system to molecular structure and geometry: crystals with a base and molecular crystals. Calculation and modelling of diffraction patterns from atomic and structure scattering factors. Solid-state polymorphism of drugs and other organic molecules. 2. Phase Equilibrium and phase transitions Thermodynamic Potentials for hydrostatic pvT systems; Maxwell relations; TdS equations; General conditions for equilibrium; Fluctuations; Le Châtelier principle. 3. Phase transitions and topological pressure-temperature phase diagram Equilibrium conditions for hydrostatic pvT systems; First-order phase transitions: Clausius-Clapeyron equation. Stability and metastability domains; High-order phase transitions. Group-subgroup phase transitions.; Critical and triple points; Topological P-T phase diagram. Calorimetry techniques. 4. Binary systems Thermodynamics of mixing, thermodynamic potential; types of binary phase diagrams: eutectic, metatectic and peritectic; solubility and miscibility; metastable and unstable states; nucleation vs spinoidal decomposition.		
Skills acquired	On successful completion of the course, the students will be able to discuss the crystallographic properties of different polymorphs, the equilibrium conditions for a phase or phase coexistence, draw multiphase and/or binary phase diagrams, and distinguish between different equilibrium, metastable, and unstable states, and their relevance for drug formulations. Students will learn to distinguish and characterize the different structural phases based on their symmetries and the relationships between them. The student will be able to apply concepts related to the thermodynamics of binary systems.		
Examination	Written exam, laboratory reports Final Exam: 80% Laboratory reports 20%		
Classification	Materials Science		

<table>
<tr><th colspan="4">TERM 2 – Polytechnic University of Catalonia (UPC) – Spain</th></tr>
<tr><td>Course name</td><td colspan="3">Molecular and soft condensed matter</td></tr>
<tr><td>Credit Points (ECTS) 3</td><td>Hours (Face-to Face in class):
Lectures: 36
Practical works: 0
Total: 36</td><td>Duration
half semester</td><td>Mode
Compulsory (Tracks 1 and 2)</td></tr>
<tr><td>Instructors</td><td colspan="3">R. Macovez, C. Alemán, M. Romanini</td></tr>
<tr><td>Contents</td><td colspan="3">(1) Basics of molecular condensed matter
1.1) Introduction on disorder & dynamics (liquids, mesophases, polymers, glasses); microscopic constituents, degrees of freedom, dynamics & disorder
1.2) statistical physics: entropy, Boltzmann statistics; partition function, energy, free energy
1.3) Mechanical & (di)electric properties: Eyring model & viscosity; elasticity & viscoelasticity; charge conduction & polarization; linear response theory in the time & frequency domains
1.4) Phase transitions, melting & crystallization, Avrami law; glass transition
1.5) Statistical models in soft matter: inter-particle interactions; hard-sphere gas, liquid & glass
(2) Single-component systems
- Structural glasses, residual entropy; Adam-Gibbs theory; relaxation & ageing
- Orientationally disordered solids, plastic crystals, Condis crystals
- Thermotropic liquid crystals: order parameter, Maier-Saupe theory, anisotropic properties
- Amorphous & semicrystalline linear polymers; Miller theory; rotational isomeric state model; Kuhn ideal chains; Rouse model, normal & segmental relaxations; viscoelasticity; reptation
- Polymers networks & rubber elasticity; conductive polymers; liquid crystal polymers; fibers
(3) Binary and multicomponent systems
- Binary systems: free energy of mixing, equilibrium phase diagrams; glass-forming mixtures
- Binary polymer systems: polymer blends; polymer solutions and gels; swelling phenomena; Flory-Huggins theory; block copolymers; water-surfactant mixtures, lyotropic liquid crystals
- Hydrogels, organogels, swelling phenomena; superhydrophobic/hydrophilic, superolephobic, superamphiphilic, and self-healing polymer coatings
- Self-assembly in condensed matter: biopolymers, helix-coil & coil-globule transitions; surfactant systems, biomembranes, emulsions; semiflexible polymers & cytoskeleton
- Applications to drug encapsulation, controlled drug release, and drug delivery</td></tr>
<tr><td>Skills acquired</td><td colspan="3">At the end of the course, students should be able to:
- based on the shape and size of its microscopic constituents, describe the types of condensed phases that can be displayed by a single-component</td></tr>
</table>

	systems, and ascertain which of them are observed at lower or higher temperature; - describe the main experimental techniques available to identify phases and study molecular dynamics and phase transitions, and explain linear response theory and its main implications - discuss the degree of disorder inherent to a condensed phase, and its main characteristic microscopic dynamic processes; discuss the role of disorder and molecular and macromolecular dynamics for rheological and mechanical properties - describe orientational order in liquid crystals, and the resulting anosoptropy of mechanical, dielectric and optical properties - use random walk models, self-similarity, entropic elasticity models and affine deformation theory to explain the properties of linear polymers, entangles polymer melts, and of polymer networks such as rubbers - describe the phenomenology of the glass transition in a number of systems ranging from atomic and molecular structural glasses to plastic crystals, to polymers and colloids - discuss the thermodynamic theory of the free energy of solutions and binary mixtures - use the concept of chemical potential to describe self-assemply in water-surfactant systems - enumerate the main technological applications of molecular and soft condensed matter systems, and discuss the relevance of soft matter to explain biological structure formation and biophysical processes.
Examination	Written final exam and homework assignments (problems and case studies) Final mark = Max{FinalExam ; 0.8*FinalExam + 0.2*Homework}
Classification	Physics-Chemistry

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain			
Course name	Large facilities: synchrotron and neutron sources		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 42 Practical works: 3 Total: 45	Duration half semester	Mode Compulsory (Tracks 1 and 2)
Instructors	P. Bruna, Y. A. Koubychine, L. C. Pardo		

Contents	Course syllabus: 1. Basics of particle accelerators 2. Generation of electromagnetic radiation 3. Examples of large facilities: colliders, ion accelerators, synchrotron radiation and spallation sources 4. The basics of X-ray and neutron scattering 5. Beamlines 6. Inelastic neutron scattering 7. Neutron applications 8. Diffraction at Synchrotron Sources 9. Fundamentals of X-ray Absorption Fine Structure (XAFS) 10. Hard X-Ray Synchrotron Imaging Techniques and other techniques 11. Frequentist data analysis 12. Bayesian data analysis
Skills acquired	Students will be able to understand the working principle of neutron and X-ray sources, and to discuss the basics of interaction and scattering of these beams with matter. Students will also acquire knowledge about existing facilities and technical equipment available to manipulate and detect particles and X-rays. In the second part of the course, students will learn which neutron- and synchrotron-radiation- based techniques (including diffraction, X-ray absorption) can be employed for different experimental goals, with particular reference to the type of information that can be extracted from each method. Also imaging methods will be covered. Finally, students will acquire skills on data and errors, and on classical fitting methods, and have hands-on experience on data analysis hypothesis testing and in the practice of model selection.
Examination	The written exams will be multiple choice tests or short exercises that will be carried out during teaching hours once the part of the syllabus to be assessed has been completed. For these individual tests, only a calculator can be used. The exercises, project and practices can be done both individually and in groups. The final mark will consist of the following items (with indicated the percent weight of each): Written exams: 40% Written assignments: 25% Project: 15% Practical work: 20%
Classification	Materials Science

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain			
Course name	Biopham short internship		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 0 Practical works: 45 Total: 45	Duration 2 months	Mode Compulsory (Tracks 1 and 2)

Instructors	The project will have a direct supervisor, who will differ from project to project, and a UPC tutor, in charge of checking that academic duties are fulfilled. The tutor is R. Macovez.
Contents	Research/industrial internship in which the students will carry autonomous research (in an experimental or computational project).
Skills acquired	After completion of the internship, the students will have hands-on, operative knowledge of a research project carried out either at a university, research institute or facility, or private company. They will actively participate in a line of research or development of a product, and become acquainted with the work environment which is the target of the Erasmus Mundus programme.
Examination	The final mark will stem from two evaluations: - Evaluation by Direct Supervisor (80% of the final mark). - Written report evaluated by Tutor (20% of the final mark)
Classification	It will depend on the project, but most Short Intership projects will be in Materials Science, Biophysics, or Physics-Chemistry.

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain			
Course name	Machine learning with neural networks		
Credit Points (ECTS) 4	Hours (Face-to Face in class): Lectures: 26 Practical works: 10 Total: 36	Duration half semester	Mode Optional
Instructors	F. Mazzanti, R. Pastor		
Contents	Course syllabus: (1) General Concepts of Learning and Neural Networks Students will receive general knowledge related to neural networks, that is, the knowledge common to any type of network, plus the biological and mathematical justification of these concepts. The classification of neural networks will be motivated and the different networks will be described in general terms. The basic concepts of machine learning and its specific implementation associated with neural networks are described (the functionality of a network is achieved through the learning of the network, given some data associated with a specific problem). (2) Feed-forward Neural Networks: Multi-layer Perceptrons, Support Vector Machines and Convolutional Networks. This first block of the course will revolve around feed-forward networks and the Backpropagation training algorithm. The three most commonly used architectures will be explained: The Perceptron and its generalization (Support Vector Machines), the multilayer perceptrons and the convolutional networks. We will emphasize the practical aspects of the subject matter, putting much		

	detail on the problems that may appear when training these networks with real problems. A practice related to the content of this block will be assessed. (3) Recurrent Neural Networks: Hopfield networks, Boltzmann Machines and LSTM This second block of the course will focus on recurrent networks, where we will see Hopfield networks and Boltzmann Machines as classic examples of recurrent network and Restricted Boltzmann Machines (RBM) and the LSTM as examples of networks used in practical problems. A practical work will be done on RBMs learning algorithm, called Contrastive Divergence (CD-k). This part includes and introduction to Deep Learning.
Skills acquired	At the end of part (1), students will be able to explain the concept of Neural Network, describe the different types of network, and the concept and peculiarities of Machine Learning. Students will acquire basic knowledge of Python to understand how neural network and Machine Learning can be implemented. After part (2), students should be able to describe multi-layer perceptions and implement the backpropagation learning algorithm. Students will understanding the mechanism of work of the Rosenblatt Perceptron and of more sophisticated machines (Support Vector Machines) They should be able to give a detailed description of Convolutional Neural Networks, and solve practical problems that may appear in the training of Neural Networks. Finally, on successful completion of part (3), students will be able to understand: - the difference between a recurrent network and a feed-forward network - the Hopfield model as a simple example of a recurrent network - the Boltzmann Machines (BM) and the concept of learning a distribution of probability - the Boltzmann Restricted Machines (RBM) and the advantages over BMs - the details of the Contrastive Divergence algorithm to train RBMs - the management of sequential data by means of LSTMs Students will also be able to relate the previously mentioned models to Deep Learning
Examination	It will be based on two aspects: - Computer assignments - Written final exam
Classification	Physics

<table>
<tr><th colspan="4">TERM 2 – Polytechnic University of Catalonia (UPC) – Spain</th></tr>
<tr><td>Course name</td><td colspan="3">Complexity in biological systems</td></tr>
<tr><td>Credit Points
(ECTS) 4</td><td>Hours (Face-to Face in class):
Lectures: 32
Practical works: 4
Total: 36</td><td>Duration
half semester</td><td>Mode
Optional</td></tr>
<tr><td>Instructors</td><td colspan="3">S. Alonso, A. Pons</td></tr>
<tr><td>Contents</td><td colspan="3">Course syllabus:
(1) Complex spatio-temporal dynamics in biology
- Oscilations, excitability, bistability
- Sinchronization in biological systems
- Stochastic biochemistry
(2) Analysis of complex biosignals
- Deterministic and stochastic signals
- Statistical properties
- Non-lineal analysis of temporal series
(3) Self-organization in biological systems
- Excitability and cardiac tissue
- Self-assembling: protein folding and membrane formation
- Cell polarization, chemotaxis and morphogenesis
(4) Biological networks
- Introduction to networks
- Networks in Biology (examples : metabolic, regulatory and signalling networks ; ecology and epidemiology networks)
- Networks in the brain</td></tr>
<tr><td>Skills acquired</td><td colspan="3">At the end of the course, students should be able to:
- Understand what a complex system is and how to characterize it
- Obtain a basic knowledge of biological phenomena, from the molecular/cellular scale to the macroscale
- Dominate numerical techniques and use specific software related with the course
- Be able to include the theoretical knowledge to solve biological problems
- Be able to present the results of a project in a written text and orally, using a precise language and putting the results in the correct context.</td></tr>
<tr><td>Examination</td><td colspan="3">The final mark for this course will be as follows:
Final mark = WT*0.6 + HW*0.4,
where WT is the mark of the written test, and HW the mark of homework assignments (applied activities, case studies, problem solving, bibliographic searches, etc.).</td></tr>
<tr><td>Classification</td><td colspan="3">Biophysics</td></tr>
</table>

TERM 2 – Polytechnic University of Catalonia (UPC) – Spain			
Course name	Stochastic methods for optimization and simulation		
Credit Points (ECTS) 4	Hours (Face-to Face in class): Lectures: 16 Practical works: 20 Total: 36	Duration half semester	Mode Compulsory track 1 Optional track 2
Instructors	J. Casulleras, G. Astrakharchik		
Contents	Course syllabus: 1. Monte Carlo integration: distribution functions and their sampling, crude Monte Carlo, rejection, variance reduction techniques, multidimensional integration, Metropolis method. 2. Monte Carlo optimization: simulated annealing, genetic algorithms. Optimal control theory 3. Application of Monte Carlo methods to many particles systems. Discrete and continuous systems. Classical simulation of condensed phase systems: simple monoatomic systems, molecular materials, bio-molecules. 4. Dynamic Monte Carlo: random paths and diffusion equation, Fokker-Planck and Langevin methods, Brownian dynamics. 5. Applications of Monte Carlo methods to quantum systems: wave functions for bosons and fermions, variational Monte Carlo, diffusive Monte Carlo, path integral Monte Carlo.		
Skills acquired	At the end of the course, students will have gained: - the ability to generate random numbers according to simple probability distribution laws, and to perform a multidimensional integral using the Monte Carlo method and correctly estimate its statistical variance ; - knowledge of the methods for reducing variance and their optimal choice according to the type of problem to be solved ; - knowledge of the techniques in optimal control theory and the ability to apply Monte Carlo methods to find the optimal solution ; - technical know-how to make a classical simulation of a multiparticle system using the Metropolis method ; - understanding of the basic theory of quantum Monte Carlo, technical know-how to build a Monte Carlo program for the calculation of its properties ; - the ability to perform multidimensional optimization using stochastic techniques, and knowledge of the main stochastic methods used in the study of quantum systems.		
Examination	The examination for this course will be based on two types of activities : presentations of practical work in the classroom using computer equipment ; and evaluable written reports. The relative weight for the final mark will be: - Oral presentation 25% - Works carried out by the student 75%		
Classification	Physics		

<table>
<tr><th colspan="4">TERM 2 – Polytechnic University of Catalonia (UPC) – Spain</th></tr>
<tr><td>Course name</td><td colspan="3">Biophysical and materials science characterization</td></tr>
<tr><td>Credit Points (ECTS) 4</td><td>Hours (Face-to Face in class):
Lectures: 30
Practical works: 6
Total: 36</td><td>Duration
half semester</td><td>Mode
Compulsory track 2
Optional track 1</td></tr>
<tr><td>Instructors</td><td colspan="3">B. Echebarria, T. Pradell</td></tr>
<tr><td>Contents</td><td colspan="3">(1) Physicochemistry of solutions
Introduction to inorganic chemical physics of electrolyte & nonelectrolyte solutions: Types of solutions. Thermodynamics of solutions (entropy, free energy and chemical potential; phase diagrams).
Properties of water: The hydrogen bond, solubility of molecules in water, polar and non-polar solvents. Electrical permeability of water. Dissociation: acids and bases, protonation.
Properties of solutions: functional groups, hydrophilic and hydrophobic interactions; solubility; diffusion. Colligative properties: boiling-point elevation, freezing point depression, osmotic pressure. Surface tension, capillarity. Water phase diagram and anomalies; aqueous electrolytes; non-electrolyte solutions. Electrostatics for salty solutions: biopolymers (polyelectrolytes) and biomembranes in water; Poisson-Boltzmann equation, Debye-Hückel model, electric double layers, ion and proton conduction; transport properties.
(2) Applications to pharmaceutics, drug formulation, & biophysical pharmacology
- Optical microscopy: bright field, dark field, fluorescence, and confocal microscopy. Super-resolution microscopy
- Experimental techniques for electrolyte and non-electrolyte solutions
- Small Molecules (drugs): HPLC, Chromatography, Mass spectroscopy, ICP-MS
- Characterization of Nanoparticles: Molecular sizes (Dynamics light scattering, DLS), Surface charge (zeta potential, with conductivity measures)
- Characterization of Biomolecules: chromatography, gel electrophoresis, Western Blot
(3) Physicochemistry of solids
Introduction to inorganic solid-state chemical physics (cohesive interactions; organic solids and salts); structural and mechanical properties of homogeneous solids; non-miscible systems: morphology and properties of phase-separated materials
(4) Laboratory techniques
- Elemental analysis: photoelectron & mass spectroscopy (XPS, UPS, Auger, secondary ion mass spectroscopy)
- Chemical analysis: optical and vibrational spectroscopy (UV-vis, IR, Raman), nuclear magnetic resonance (NMR)
- Morphological analysis: contact angle, powder X-ray diffraction (XRD), tomography (microCT), NMR-imaging, electron microscopy (SEM, TEM, energy loss/secondary electron spectroscopy)</td></tr>
</table>

	- Phase-change analysis - Mechanical, electrical and optical characterization - A pharmaceutical application: optical measurement of the dissolution kinetics and solubility of a drug
Skills acquired	At the end of the course, students should: - be able to understand the fundamentals of electrolyte and non-electrolyte solutions, including technical literature in this field ; - have knowledge and understanding of different experimental techniques used in biophysical characterization ; - understand the fundamentals of solid-state physical chemistry, including technical literature in this field ; - understand, and know how to use different experimental techniques of materials characterization.
Examination	To compute the mark of the course, the professors will consider hand-in exercises (HE), a project during the first part of the course (P), laboratory reports (LR), and a final exam (FE). The final mark (FM) for a student will be calculated according to the formula: FM=0.15*HE+0.2*P+0.35*LR+0.3*FE
Classification	Physics-Chemistry

TERM 3 – University of Pisa (UNIPI) – Italy				
Course name	**Classification**	**ECTS**	**Hours face-to-face in class**	**Compulsory/optional Recommendation**
Biomaterials for Pharmaceutical Applications	Materials Science	6	60	Compulsory
Nanomedicine and Regenerative Medicine	Materials Science	6	48	Compulsory
Manufacturing of polymers and nanocomposites for biomedical application	Materials Science	3	24	Optional (6 ECTS must be chosen in this group)
Surface Physics	Physics	3	24	
Solid state NMR spectroscopy in pharmaceutical and material science	Chemical Physics	6	48	
Introduction to optical spectroscopy	Physics	6	48	
Multi-scale modelling in materials design	Materials Science	6	48	Optional (6 ECTS must be chosen in this group);recommended for students who took Computational Materials Science at term 1
In Silico Models for drug-design techniques	Pharmaceutical chemistry	6	48	Optional (6 ECTS must be chosen in this group); recommended for developers of in silico models for biomedi
Bioinformatcs and System Biology	Pharmaceutical chemistry. Biochemistry, Computer Science	6	48	Optional (6 ECTS must be chosen in this group); recommended for users of ML software
European Responsible Research and Innovation	Soft Skills	3	30	Optional (3 ECTS must be chosen in this group); recommended for students interested in research in public sector
Health Entrepreneurship Programme	Soft Skills	3	30	Optional (3 ECTS must be chosen in this group);recommended for students interested in research in private sector
Joint advanced winter course	Soft Skills	3	24	Compulsory
TOTAL		**30**	**258**	

<table>
<tr><th colspan="4">TERM 3 – University of Pisa (UNIPI) – Italy</th></tr>
<tr><td>Course name</td><td colspan="3">Biomaterials for Pharmaceutical Applications</td></tr>
<tr><td>Credit Points
(ECTS) 6</td><td>Hours (Face-to Face in class):
Lectures: 48
Practical works: 12
Total: 60</td><td>Duration:
12 weeks</td><td>Mode
Compulsory (Tracks 2)</td></tr>
<tr><td>Instructors</td><td colspan="3">Serena Danti</td></tr>
<tr><td>Contents</td><td colspan="3">1. Fundamentals of Pharmaceutical Biomaterials
Classes of biomaterials (natural/synthetic), biocompatibility, biodegradability, and drug–material interactions.
2. Drug Delivery Systems
Mechanisms of controlled and targeted release; polymeric carriers, nanoparticles, hydrogels, and liposomes; applications in oral, transdermal, and injectable formulations.
3. Smart and Responsive Biomaterials
pH-, thermo-, photo-, and magneto-responsive systems; self-healing and bioinspired materials for on-demand drug release and regenerative therapies.
4. Tissue Engineering and Biofabrication
Scaffolds for tissue repair, injectable hydrogels, and drug-eluting constructs; 3D bioprinting and bioink design for regenerative medicine.
5. Biomaterials in Drug Screening
Material design for in vitro models, microfluidic platforms, and sensor-integrated systems for pharmacological testing.
6. Characterization and Evaluation
Physicochemical and biological characterization, release kinetics, degradation, cytocompatibility, and ethical/regulatory aspects.</td></tr>
<tr><td>Skills acquired</td><td colspan="3">On successful completion of the course, students will be able to design and evaluate biomaterials for controlled drug delivery, tissue regeneration, and pharmaceutical testing platforms; understand and apply mechanisms of drug–material interactions; critically assess the performance and safety of bioresponsive systems; and integrate materials science, biology, and pharmaceutical principles to develop innovative, biocompatible therapeutic materials.</td></tr>
<tr><td>Examination</td><td colspan="3">Oral exam, laboratory reports
Final Exam: 50%
Assignments: 50%</td></tr>
<tr><td>Classification</td><td colspan="3">Materials Science</td></tr>
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<table>
<tr><th colspan="4">TERM 3 – University of Pisa (UNIPI) – Italy</th></tr>
<tr><td>Course name</td><td colspan="3">Nanomedicine and Regenerative Medicine</td></tr>
<tr><td>Credit Points (ECTS) 3</td><td>Hours (Face-to Face in class):
Lectures: 48
Practical works:
Total: 48</td><td>Duration:
12 weeks</td><td>Mode
Compulsory (Tracks 2)</td></tr>
<tr><td>Instructors</td><td colspan="3">Caterina Cristallini</td></tr>
<tr><td>Contents</td><td colspan="3">Nanomedicine: basic concepts and history
Nanotechnology in nanomedicine
Nanomaterials: classifications and properties
Passive, active, and physically activated targeting strategies
Nanovectors for controlled drug release
Nanovectors for overcoming biological barriers
Nanovectors for cell stimulation
Non-viral nanovectors for gene therapy
Nanovectors for cell therapy
Theragnostic nanomedicine</td></tr>
<tr><td>Skills acquired</td><td colspan="3">At the end of the course the following skills will be acquired:

• ability to design nanovectors for use in molecular, cellular and animal biology
• The student will understand the benefits of using nanovectors compared to traditional approaches
• The student will become aware of the use of nanovectors in commercial kits for molecular biology or in FDA drugs (or drugs in the clinical trials)
• Critical assessment of issues to be addressed and possible strategies for the synthesis and characterization of nanovectors</td></tr>
<tr><td>Examination</td><td colspan="3">Oral exam. The oral examination consists of an interview between the candidate and the teacher/s. During the oral examination the candidate may also be asked to solve "think as a scientist" or to try to approach an experimental problem with the right scientific plan.</td></tr>
<tr><td>Classification</td><td colspan="3">Materials Science</td></tr>
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<table>
<tr><th colspan="4">TERM 3 – University of Pisa (UNIPI) – Italy</th></tr>
<tr><td>Course name</td><td colspan="3">Manufacturing of Polymers and Nanocomposites for Biomedical Application</td></tr>
<tr><td>Credit Points (ECTS) 3</td><td>Hours (Face-to Face in class):
Lectures: 24
Practical works: 6
Total: 30</td><td>Duration:
12 weeks</td><td>Mode
Choice Optional (6 ECTS must be chosen in the green group) (Tracks 2 and 3)</td></tr>
<tr><td>Instructors</td><td colspan="3">Serena Danti, Mario Milazzo</td></tr>
<tr><td>Contents</td><td colspan="3">1. Composites and Nanocomposites
Introduction to composite materials: classification by matrix and filler, advantages, and structural design. Natural multiscale composites (bone, wood) as models for engineering. Reinforcement mechanisms in particle- and fiber-reinforced composites; interfacial adhesion, coupling agents, and rule-of-mixtures. Nanocomposites in biomedicine: mechanical reinforcement, bioactivity, tissue engineering, and drug delivery.
Overview of carbon-based nanomaterials (nanodiamonds, fullerenes, carbon nanotubes) and boron nitride nanostructures; functionalization strategies for dispersion and biocompatibility. Biomedical applications: imaging, sensors, photothermal and photodynamic therapies, antioxidant activity, and cellular stimulation. Processing methods (e.g., solvent casting) and nanotoxicity considerations.
2. Additive and Biofabrication Technologies
Principles of Additive Manufacturing (AM): comparison with traditional methods, workflow (design–printing–post-processing), and main AM techniques (FDM, SLS, SLA, LOM).
Introduction to 4D printing and smart polymers: stimuli-responsive hydrogels, thermo-, photo-, and piezo-responsive materials, and shape-memory polymers.
Biofabrication and 3D bioprinting: tissue engineering paradigm (cells–scaffold–stimuli), rheological design of bioinks (shear-thinning, viscoelasticity), printability–cytocompatibility trade-offs, and post-printing crosslinking and characterization.
3. Fiber Processing and Biomedical Textiles
Polymer fiber production: melt-, dry-, wet-, and dry-jet-wet spinning.
Electrospinning and melt electrowriting for nanofiber fabrication; process parameters, collector design, and nanofiber yarn formation.
Biocompatible, bioactive, and electroactive fibers for wound healing, drug delivery, and tissue regeneration. Medical textiles: design criteria, fiber properties, and biomedical applications of bio- and electroactive polymer/ceramic nanofibers (e.g., in cochlear or bone regeneration).</td></tr>
<tr><td>Skills acquired</td><td colspan="3">On successful completion of the course, students will be able to understand and design polymeric and composite materials for biomedical use; analyze structure–property relationships in macro-, micro-, and nanocomposites; select and optimize manufacturing processes including additive manufacturing, 4D</td></tr>
</table>

	printing, and electrospinning; develop and characterize smart and bioactive materials for tissue engineering, drug delivery, and medical devices; and critically assess material performance, processing–structure interactions, and biocompatibility for safe and effective biomedical applications.
Examination	ORAL exam, laboratory reports Final Exam: 50% Laboratory reports 50%
Classification	Materials Science

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	Surface Physics		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 24 Practical works: Total: 24	Duration 1 semester	Optional
Instructors	Massimiliano Labardi		
Contents	PART I: Phenomenology of surfaces and interfaces Introduction to the course. Introduction to surfaces and interfaces. Surface/volume ratio. Microscopic interpretation of intermolecular forces. Interaction energy between ions, frozen and mobile permanent dipoles. Keesom energy. Interaction energy with induced dipoles: Debye induction energy, London dispersive energy. Ionization energy. Van der Waals energy. Additivity of Van der Waals interaction. VdW forces between macroscopic bodies: adsorption, adhesion, cohesion. Hamaker constant. Liquid surfaces. Interfacial thickness. Surface free energy and surface energy. Surface tension. Thermodynamics of interfaces in equilibrium: Gibbs theory. Definition of interface and Gibbs dividing plane. Interfacial excess. Thermodynamic potentials at the interface. Thermodynamic definition of surface tension. Euler relation and Gibbs-Duhem relation. Surface tension and interfacial excess. Mixing entropy and mixing chemical potential. Surface activity: case of ionic, apolar, and amphiphilic solutes. Colloidal aggregates. Critical micellar concentration. Thermodynamics of colloidal aggregation. Pressure difference across a curved surface: Young-Laplace equation. Vapor pressure at a curved surface: Kelvin equation. Supersaturation pressure. Theory of homogeneous nucleation. Heterogeneous nucleation. Wetting. Wetting line and contact angle. Young equation. Cases of partial, complete, and no wetting. Capillarity phenomena. Thin film formation. Dewetting. Pseudo partial wetting and wetting layer. Thin film deposition: dip coating and spin coating. PART II: Surface characterization techniques		

	Scanning probe microscopy. Beam vs local probes. Atomic force microscope. Working principle: typical setup. Piezoelectric scanners and raster scan. Constant height mode and constant force mode. Interaction steepness and atomic resolution. Cantilever force sensors. Optical lever deflection detection method. Static mode of operation: contact mode. Jump-in-contact and jump-off-contact points. Lateral force and local friction coefficient measurement. Bidirectional optical lever. Dynamic modes of AFM. Problems arising in static mode: thermal noise. Response function of the cantilever as a simple harmonic oscillator. Tapping mode. Phase sensitive coherent detection and lock-in detection. Effect of conservative and dissipative interactions on resonance curve. Frequency-modulation mode. Piezoelectric resonant force sensors: quartz tuning fork. Combined scanning probes. Auxiliary distance control. Electrostatic Force Microscopy. Dependence of electric force on distance and electric properties of dielectrics. Voltage-modulated force detection. Dielectric constant, surface charge and contact potential measurement. Kelvin probe method. Kelvin probe force microscopy. Nanotribology. Friction at a contact point measured by AFM. Stick-slip model for dissipation by dynamical friction. Friction of atomic layers. Quartz crystal microbalance (QCM). Gravimetric and non-gravimetric QCM. Interfacial viscosity and slip time.
Skills acquired	The development of a critical spirit and synthesis aimed at identifying the fundamental concepts underlying the the physics of surfaces and interfaces is promoted. The students that attend this course will be able to explore and understand the physical phenomena that underpin the most important techniques and methods of analysis of surfaces.
Examination	Oral exam
Classification	Physics

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**Solid state NMR spectroscopy in pharmaceutical and material science**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 48 Practical works: Total: 48	Duration 1 semester	Mode Optional
Instructors	Francesca Martini – Marco Geppi – Silvia Borsacchi		
Contents	Basics of molecular spectroscopy: the electromagnetic spectrum, electromagnetic radiations and their interaction with molecules (absorption,		

	emission, scattering), energy levels and different types of transitions, populations of the energy levels at the thermal equilibrium. Brief overview of the different spectroscopic techniques: Nuclear Magnetic Resonance (NMR), Electron Paramagnetic Resonance, Optical, Raman, Photoelectronic, and Mossbauer spectroscopies. Basic theory of NMR: the nuclear spin, nuclear interactions, relaxation times. NMR applied to the solid state: peculiarities, comparison with solution state NMR, the role of anisotropies. 1D low- and high-resolution experiments, 2D separation and correlation techniques. Spin diffusion. Applications of solid state NMR to the study of the structure and dynamics of several classes of materials: pharmaceuticals, porous materials, materials for energy, biomaterials, etc.
Skills acquired	At the end of the course: • the student will have acquired an in-depth understanding of the fundamental concepts of spectroscopy, with a particular focus on solid-state Nuclear Magnetic Resonance, including theoretical aspects, experimental techniques, and main applications; • the student will be able to deliver an oral presentation on the topics covered during the course, using appropriate scientific language.
Examination	Oral exam
Classification	Chemical Physics

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**Introduction to optical spectroscopy**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 44 Practical works: 4 Total: 48	Duration 1 semester	Mode Optional
Instructors	Alessandra Toncelli		
Contents	Basics of radiation/matter interaction and understanding of emission/absorption spectra of substances in the range near-UV - IR, up to the THz range. Technical and conceptual tools for emission, absorption, Raman spectroscopy. Energy levels of the main physical systems: electronic levels in atoms and molecules, rotational and vibrational levels of molecules, Lorents-Drude model, electronic levels of impurities (transition metals and rare earths) in crystals, electronic and fononic bands in crystals. Application of spectroscopy techniques to the analysis of organic molecules, with specific examples from pharmaceutical and biopharmaceutical materials		

Skills acquired	On successful completion of the course students will gain the ability to analyse problems of optics involving nanomaterials and biomaterials, both for the analysis at the local scale and for the exploitation of their specific properties in devices and approaches. Although the major emphasis is put onto the physical aspects, the course fosters the development of cross-disciplinary abilities, directly connected with other scientific areas, for example to the pharmaceutical research.
Examination	Oral exam
Classification	Physics

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**Multi-scale modelling in materials design**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 48 Practical works: Total: 48	Duration 1 semester	Mode Optional
Instructors	Samuele Giannini – Giacomo Londi		
Contents	The course will review the fundamental computational approaches for materials modeling in the framework of a hierarchical multi-scale paradigm: first-principles methods, classical and reactive molecular dynamics, coarse-grained methods and continuum methods. The basic theory at the base of each approach will be outlined with a quick summary of the main (open-source) codes available for each described computational method. By reviewing the latest advances in the scientific literature, it will be shown how multi-scale computational modeling is gaining a pivotal role in the field of computational materials science and how it is used to understand and design new structures and new materials following a “bottom-up” approach from atomistic to real-world scale resolution. In the perspective of applying multi-scale modeling to the investigation and design of materials for technological applications with peculiar response properties, the attention of the course will be put on basic structure/property relationships applied to a variety of both inorganic (nano-composite) and bio-based materials.		
Skills acquired	At the end of the course, the student will be able to: • evaluate a suitable modeling strategy for a material relevant to their work, selecting the most appropriate approach within a multiscale hierarchical framework; • understand the modeling activity described in a scientific article that may be relevant to their research; • engage in a productive dialogue with a scientist or engineer working in		

	the field of computational materials science, in order to assess the potential value of modeling in the development of a material of interest for their own activities.
Examination	Oral exam
Classification	Materials Science

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	In Silico Models for drug-design techniques		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 48 Practical works: Total: 48	Duration 1 semester	Mode Optional
Instructors	Giulio Poli		
Contents	The course aims to provide the basic elements of in silico modeling of biological and physio-pathological systems. In particular, the course will deal with the objectives and tools for the formulation of theoretical models, the computational techniques for their simulation and for parameters identification using experimental data. Specifically, the course will focus on in silico models for protein analysis, basic in silico drug-design techniques and chemometric analyses able to support in vivo toxicity studies. The main objective is to provide the student with conceptual and operational tools that allow him/her to develop the entire modeling process for some significant biomedical applications.		
Skills acquired	The student who completes the course will demonstrate an advanced understanding of ligand-protein and protein-protein interactions. He/she will be familiar with a broad range of ligand- and receptor-based computational methods, and finally he/she will be able to perfom computational modeling tasks using state of the art software.		
Examination	Written test and oral interview.		
Classification	Pharmaceutical chemistry		

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**Bioinformatics and System Biology**		
Credit Points (ECTS) 6	Hours (Face-to Face in class): Lectures: 48 Practical works: Total: 48	Duration 1 semester	Mode Optional
Instructors	Paolo Milazzo, Silvia Galfrè, Eleonora da Pozzo, Giulio Poli		
Contents	1) Biological background. General principles of cellular biochemistry. General principles of molecular biology. 2) Applications to drug discovery and drug design. Basis of computer-aided drug design. Molecular Dynamics simulations in drug design. Laboratory on Ligand-protein graphical representation (UCSF Chimera) and MD simulations (Amber22) 3) Analysis of biological data. From Reads to Sequence: Assembly Algorithms in the 3 generations of sequencing platforms. Comparison of sequences: Alignment (local or global): definitions; optimal alignment, alignment scores, Substitution Matrices. Exact alignment algorithms: dynamic programming. Heuristic algorithms (BLAST, FASTA), similarity searches in databases. Multiple alignments. Phylogenies and pattern inference. Transcriptome analysis: Annotation of alternative genes and transcriptomes. Analysis of RNA-seq data 4) Systems biology: the role of models. Modelling and analysis of (bio)chemical reaction networks. ODE and stochastic modeling approaches, simulation based on numerical integration, Gillespie algorithm and its variants. Graphical representation of reaction networks and biochemical pathways (e.g. in terms of Petri nets) and related analysis approaches. Flux balance analysis of metabolic pathways. Modelling and analysis of gene regulation networks. Boolean network models of gene regulation: simulation methods and attractor analysis, variants of Boolean networks. Inference of Boolean network models. Protein-Protein Interaction (PPI) networks. Proteomics and protein interactions, protein interaction databases, protein interaction prediction methods. Identification of modules in PPI networks. Network-based analysis of PPI networks and applications to drug target discovery. Hints on protein structure and function prediction.		
Skills acquired	Application of computational biology analysis methods and design of computational analysis pipelines		
Examination	written exam on the biological background and final exam with on both theoretical knowledge and practical skills		
Classification	Pharmaceutical chemistry. Biochemistry, Computer Science		

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**European Responsible Research and Innovation**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 24 Practical works: 6 Total: 30	Duration 1 semester	Mode Optional
Instructors	(G. Brunori – V. Mangano) to be defined		
Contents	**Foundations of RRI** – Concepts, EU policy background, and relevance to biomedical innovation. **Research Ethics and Integrity** – Good scientific practice, data transparency, preclinical ethics, and dual-use concerns. **Sustainability and Societal Impact** – Environmental responsibility, circular design of biomaterials, and patient-centered innovation. **Stakeholder Engagement and Communication** – Collaboration with clinicians, patients, and industry; open science and responsible dissemination. **RRI in Practice** – Case studies in nanomedicine, regenerative scaffolds, and drug delivery systems; integrating RRI into project design and EU funding proposals.		
Skills acquired	On successful completion, students will be able to: • Understand and apply RRI principles to biomaterials and pharmaceutical research. • Identify and analyze ethical, environmental, and societal challenges in biomedical innovation. • Integrate responsible approaches in design, testing, and communication of bio- and pharma-materials. • Collaborate and communicate effectively with multidisciplinary stakeholders in a transparent, ethical, and sustainable manner.		
Examination	Practical case discussion.		
Classification	Soft skills		

TERM 3 – University of Pisa (UNIPI) – Italy			
Course name	**Health Entrepreneurship Programme**		
Credit Points (ECTS) 3	Hours (Face-to Face in class): Lectures: 24 Practical works: 6 Total: 30	Duration 1 semester	Mode Optional

Instructors	Stefano Linari, Elena Fasil
Contents	**Innovation in Health & Life Sciences** – Overview of the health-tech ecosystem and successful startup cases. **From Idea to Market** – Identifying needs, value creation, IP, and regulatory awareness. **Business Models & Funding** – Startup development, financing options, and commercialization strategies. **Entrepreneurial Skills & Leadership** – Team building, risk management, and ethical entrepreneurship. **Pitching & Strategy** – Preparing concise business plans and investor presentations.
Skills acquired	On successful completion, students will: • Understand the process of innovation in health and pharmaceutical technologies. • Evaluate the commercial, ethical, and regulatory aspects of biomedical entrepreneurship. • Develop entrepreneurial and leadership skills for team-based innovation. • Translate research ideas into viable business or societal impact strategies.
Examination	Practical case discussion
Classification	Soft skills