LIGHT Sciences and Technologies

Master program

Curriculum

2024-2025 academic year

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LIGHT Sciences and Technologies program

Table of contents

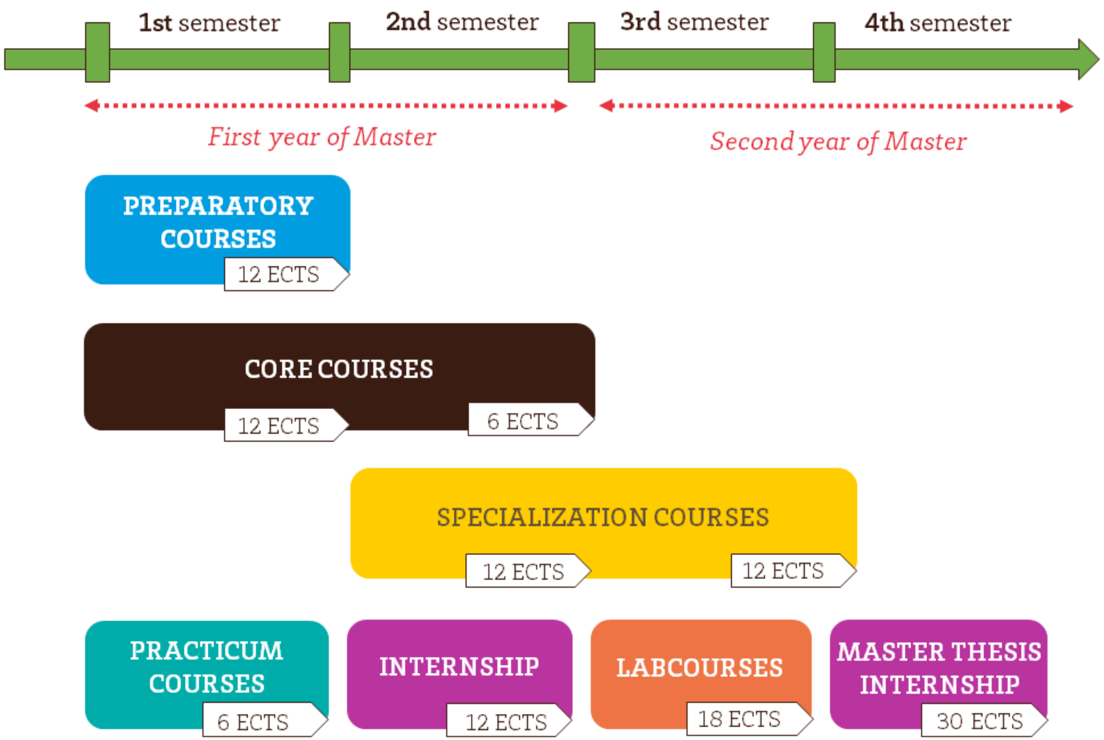
Introduction

The **LIGHT Sciences & Technologies** (LIGHT$^{S\&T}$) graduate program is an integrated, interdisciplinary program, taught by experts from both academia and industry. The Master is part of a cross-disciplinary research environment, geared to the careers of the future in the photonics industry.

The curriculum and the timetable of LIGHT$^{S\&T}$ two-year Master program are structured so that it encourages interdisciplinarity and international mobility and facilitates students' early integration into research laboratories.

The curriculum is constituted of:
- **Preparatory courses** which help to bring students of different backgrounds to the required level to follow the core and specialization courses;
- **Core courses** which provide a comprehensive education in laser systems, light matter interaction and simultaneously give a review of photonics and materials properties and technology;
- **Practicum courses** which introduce experimental techniques in optics and photonics, lasers and spectroscopy, microscopy, photonic materials and chemistry, as well as biophotonics;
- **Specialization courses** selected into a large panel of specialization subjects reflecting the main research areas of the University of Bordeaux campus;
- From the second semester, students dedicate part of their time between an **internship research subject and lectures**. During the third semester, laboratory courses which are personalized laboratory training courses are held in the state-of-the-art infrastructures and facilities. The fourth semester is dedicated to a Master thesis internship.

Organization of LIGHTS&T Graduate Program



LIGHT Sciences and Technologies

Light, Matter and iNteractions

Pr. Philippe Tamarat – Academic coordinator

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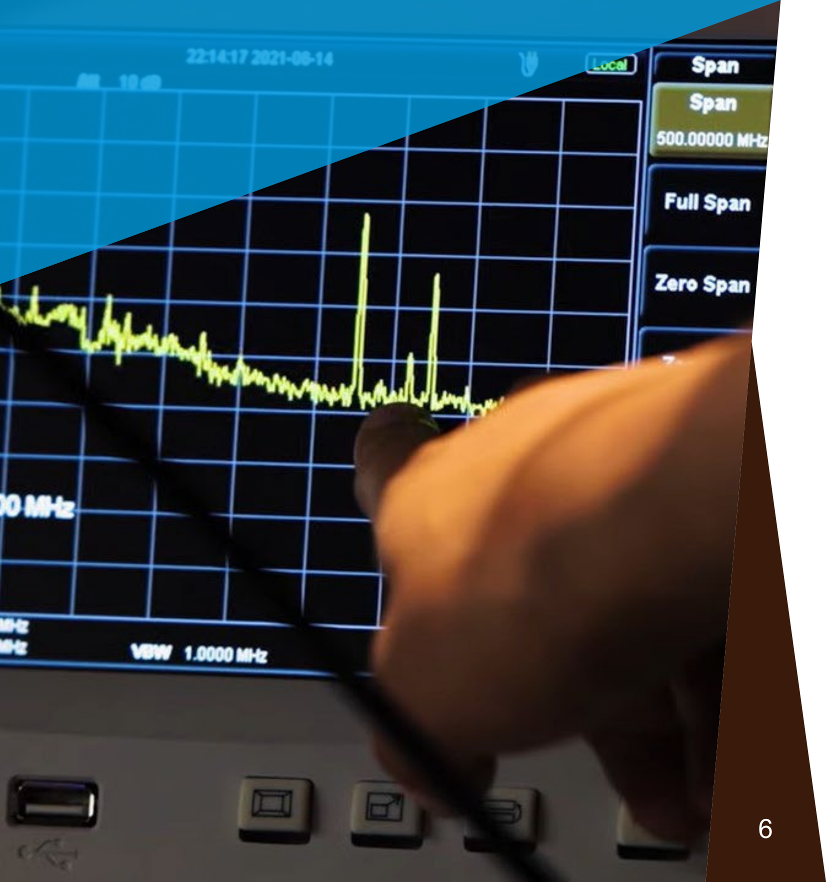
Light, Matter and iNteractions



COURSE OVERVIEW
1st year – Fall semester (S7)

PREPARATORY COUSES – 12 ECTS
- Statistical Physics and Thermodynamics (6 ECTS)
- Electrodynamics (3ECTS)
- Lab programming (3ECTS)
- Optical microscopy (3 ECTS)
- Introduction to cell biology (3 ECTS)

CORE COURSES – 12 ECTS
- Advanced quantum mechanics & light-matter interaction (6 ECTS)
- Laser Physics (3ECTS) and Nonlinear Optics (3ECTS)

PRACTICUM COURSES – 6 ECTS
- High resolution atomic spectroscopy
- Lasers and nonlinear optics
- Quantum sensing

Ligth, Matter and iNteractions

1st year – fall semester

Preparatory courses

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Statistical Physics and Thermodynamics

MICRO CANONICAL ENSEMBLE
- Statistical theory.
- Applications: paramagnetic crystal.

CANONICAL ENSEMBLE
- Partition function; free energy.
- Fluctuations;
- Applications: oscillator, polymers, interfaces (fluid, perfect gas...)
- Cumulant generating function; Special correlations.

GRAND CANONICAL ENSEMBLE
- Partition function; Grand potential.
- Applications: quantum gases.

PHENOMENOLOGY OF PHASE TRANSITIONS
- Order parameter.
- Latent heat and first order transitions.
- Metastable phases.
- Clausius-Clapeyron formula.
- Vapor pressure.

INTERACTION SYSTEMS
- Classical particles.
- Models on networks – Ising.

APPROXIMATION OF AVERAGE FIELDS
- Varational Principle of Feynman.
- Applications: Ising model, gas on networks.
- Molecular field approximation.
- Van der Waals gas.

ONE-DIMENSIONAL STATISTICAL PHYSICS
- Transfer matrices.
- Ising model Correlation functions, correlation length and magnetic susceptibility.

Electrodynamics

ELECTODYNAMICS OF VACUUM

– Maxwell equations for potentials, Lorentz transformations for potentials and fields.
– Relativistic mechanics, quadrivectors, vector and scalar potentials, charge and current densities.

DELAYED POTENTIALS

– Delayed potentials: general shape and case of an accelerated charge.
– Radiated fields and radiated energy. Spectral and angular distribution of radiation.

ACCELERATION PARTICLE RADIATION

– Braking radiation .
– Non-relativistic and relativistic gyromagnetic radiation.
– Thomson scattering.

ELECTROMAGNETIC PROPERTIES OF A DIELECTRIC MEDIUM

– Dielectric permittivity and its properties. Energy of electromagnetic waves.
– Propagation of wave packet in dispersive medium, group velocity and phase velocity.
– Dielectric permittivity at high frequencies.
– Envelope equation.

PROPAGATION OF FAST PARTICLES

– Slowing of a charged particle in a dielectric medium, friction force.
– Cherenkov effect: emission intensity and angular radiation pattern. Transient radiation.

Lab programming

This course provides some basics in programming for running and analyzing laboratory experiments in common languages.

INTRODUCTION TO LABVIEW

- General presentation of Labview: why Labview.
- Data acquisition.
- Instrument control.

INTRODUCTION TO MATLAB

- General presentation of Matlab. Why Matlab?
- Basic structure of algorithms.
- Image processing.
- Analysis tools.
- Plotting data.

INTRODUCTION TO PYTHON

- General presentation of Python. Why Python.
- Basic structure of algorithms.
- Image processing.
- Analysis tools.
- Plotting data.

Introduction to Cell biology

This course is an introduction to biology intended for non-biologists.

- **Evolution, type of cells and organisms** (tree of life).
- **Structure of a cell.**
- **Metabolism of the cell.** Thermodynamics, energetics (Krebs cycle etc.).
- **Cell division, cell death**.
- **Genetics, chromosomes and DNA**.
- **Stem cells.**
- **Proteins**: Protein synthesis & degradation, protein structure (representation, folding etc.), protein function, enzymatic activities, major signal transduction pathways.
- **Membrane biophysics.**
- **Beyond the cell:** Development, embryology, Multi-cellular organisms, systems biology (organs), Cell-cell communication: electrical excitability of neurons (introduction of).
- **Modern molecular biology tools and methods.**

PROJECT: the cell viewed by a biologist / chemist /physicist /engineer

Optical microscopy

BASIC ELEMENTS OF A MICROSCOPE

- Lens, lens combinations, magnification, image formation, Optical aberrations. Numerical aperture and resolution.
- A key element of the microscope: the objective.

CONTRAST MECHANISMS IN WHITE LIGHT MICROSCOPY

- Koehler illumination and bright field microscopy; Dark field microscopy; Strioscopy and Phase contrast microscopy.
- Differential interference microscopy.

FLUORESCENCE MOLECULAR SPECTROSCOPY

- Fluorescent molecules: Absorption and emission spectra; Fluorescence rate, saturatio. Quantum dots and other nanoparticles (diamond etc.): Absorption and emission spectra; Fluorescence rate, saturation. Intrinsically fluorescent biomolecules. Autofluorescent proteins.

FLUORESCENCE MICROSCOPY (LINEAR)

- Wide field vs Confocal Microscopy. Spinning disk confocal microscopy. Total internal fluorescence microscopy.

BASIC NOTIONS ABOUT THE CONCEPT OF EXTRINSIC PROBES AS OPTICAL REPORTERS

- Fluorescent dyes, luminescent/non luminescent particles, fluorescent proteins. Introduction to labelling strategies, immuno, chemical …
- Notions of specificity, affinity, covalence, stoichiometry. Implications about quantitative microscopy.

NON-LINEAR FLUORESCENCE MICROSCOPY

- 2-photon, 3-photon excitation fluorescence microscopy. Second/third harmonic generation.

SIGNAL SENSITIVITY, QUANTITATIVE FLUORESCENCE MICROSCOPY, SPATIAL RESOLUTION

- Origin of signal-to-noise ratios. Photon statistics and Instrumentation. Single molecule detection. The concept of sub-pixel/subdiffraction localization.

ADAPTATIVE OPTICS IN MISCROSCOPY

FLUORESCIENCE LIFETIME IMAGING MICROSCOPY. TIME CORRELATED PHOTON COUNTING

REVEALING DIPOLES INTERACTIONS BY MICROSCOPY: FOERSTER RESONANT ENERGY TRANSFERT

DYNAMIC MEASUREMENTS: TIME RESOLUTION

- Confocal vs wide-field microscopy. Fluorescence recovery after photobleaching and related methods.
- Fluorescence correlation spectroscopy. Single particle/molecule tracking.

RAMAN BASED MICROSCOPY

- Concept. Coherent Antistockes Raman Scattering. Surface enhanced Raman spectroscopy. Stimulated Raman Scattering.

PHOTOACOUSTIC MICROSCOPY
OPTICAL COHERENCE TOMOGRAPHY
BASICS OF LIGHT-MATTER INTERACTION: ABSORPTION AND SCATTERING (MIE, RAYLEIGH).
QUANTITATIVE PHASE IMAGING

Ligth, Matter and iNteractions

1st year – fall semester

Core courses

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Advanced quantum mechanics and Light matter interactions

APPROXIMATION METHODS IN QUANTUM MECHANICS
- Perturbation theory, variational method
- Application to the Stark effect and the Zeeman effect for a one-electron atom

QUANTUM TREATMENT OF A CHARGED PARTICLE IN AN ELECTROMAGNETIC FIELD
- Hamiltonian of a charge particle in an electromagnetic field
- Quantification principle of Feynman
- Aharonov-Bohm **effect**

FINE STRUCTURE AND HYPERFINE STRUCTURE OF ONE-ELECTRON ATOMS SYSTEMS OF IDENTICAL PARTICLES
- Indistinguishability, exchange operator
- Pauli principle, independent fermions and bosons at low temperature
- Stimulated emission and laser effect
- Application to polyelectronic atoms

ENTANGLED STATES, EPR PARADOX AND BELL INEQUALITY, EXPERIMENTAL TESTS, APPLICATIONS

ELEMENTS OF MOLECULAR STRUCTURE
- Born-Oppenheimer approximation
- Bonding and anti-bonding states, rotational and vibrational spectra

CLASSIC ELECTRODYNAMIC MODELS OF ATOM-RADIATION INTERACTION
- Different atom-radiation interaction processes
- Elastically bound electron model, scattering cross section

SEMI-CLASSIC ATOM-LASER INTERACTION MODELS
- Interaction Hamiltonian, selection rules
- Theory of time-dependent perturbation
- Fermi's Golden Rule - Formalism of the state vector
- Formalism of the Bloch vector. Rabi oscillations
- Relaxation processes
- Method of the effective Hamiltonian. Coupling of a discrete state to a continuum. Application to spontaneous emission.

APPLICATIONS
- Spectroscopy (in connection with the practicum course on the hyperfine levels of cesium), laser cooling …

Laser physics & nonlinear optics

INTORUDTION TO LASER: brief history, generalities, characteristics of laser light.

LASER CAVITIES AND GAUSSIAN BEAMS: ABCD matrices, stability, transverse modes, Gaussian beams and propagation.

AMPLIFICATION: absorption and emission, homogeneous and inhomogeneous enlargements, rate equations, population inversion in 3 and 4-level systems, Gain.

LASER OSCILLATION: Threshold condition, hole burning, frequency pulling, evolution equations, power output and optimal coupling.

MODES OF OPERATION: single mode / multimode, continuous / pulsed, mode selection, brief introduction to Q-switching and locking mode.

LASER TECHNOLOGY AND OPTICAL INSTRUMENTATION: pumping, birefringent optics, modulators, notions of nonlinear optics, characterization tools.

TYPES OF LASERS AND APPLICATIONS with a focus on semiconductor lasers.

INTRODUCTION TO NON-LINEAR OPTICS.

SECOND-ORDER NON-LINEAR: sum frequency generation, Manley-Rowe relations, parametric down-conversion, optical parametric oscillator.

THIRD-ORDER NON-LINEAR EFFECTS: Optical Kerr effect, Self-phase modulation, soliton propagation, Four-wave mixing, Phase conjugation mirrors, stimulated diffusion (Raman, Brillouin, Rayleigh).

Ligth, Matter and iNteractions

1st year – fall semester

Practicum courses

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High resolution atomic spectroscopy

- Single-mode tunable laser (diode laser).
- Absorption spectrum of an atomic vapor (Cesium atoms).
- Inhomogeneous broadening due to Doppler effect at room temperature.
- Emission spectrum of atomic vapors.
- Saturated absorption spectroscopy of atomic vapors.
- Measurement of the homogeneous linewidth of electronic transitions.
- Zeeman effect, Faraday effect.

Lasers and nonlinear optics

INTRODUCTION SESSION TO BASICS OF OPTICS

- Gaussian beams.
- Optical resonators.
- Laser cavities.
- Nonlinear optics.
- Parametric cavities and nonlinear gain.

PRACTICUM#1 – OPTICAL RESONATORS AND SECOND HARMONIC GENERATIONS

- Basics of laser cavities: the Helium – Neon laser.
- Laser amplification.
- Passive cavities: the case of Fabry-Perot etalon.
- Second harmonic generation: an insight in non-linear optics.

PRACTICUM#2 – DIODE-PUMPED Nd:YAG LASER CAVITY

- Diode pump characterization.
- Laser cavity stability, resonant laser mode and mode-matching.
- Laser slope: laser threshold and laser efficiency.
- Intra-cavity second harmonic generation.

PRACTICUM#3 – OPTICAL PARAMETRIC OSCILLATOR (OPO)

- Parametric cavity stability, resonant parametric mode and mode-matching.
- Phase-matching characterization and polarization dependence.
- Non-linear slope: parametric threshold and parametric efficiency.
- Application of the pulsed beams to time-resolved spectroscopy.

FINAL SESSIONS – MODELLING OF SOME ASPECTS (DEPENDING ON MEASURED DATA)

- Geometry of resonant laser and/or parametric Gaussiand beams.
- Angular spectral acceptance of second harmonic generation.
- Emission threshold and gain efficiency (laser and/or parametric cavity).
- Rare-earth lifetime.

Quantum Sensing

- Nitrogen-Vacancy (NV) defects in diamond.
- Spin and optical properties of NV centers.
- Optically detected magnetic resonance (ODMR).
- Fundamentals of magnetic field measurement with NV centers in diamond.

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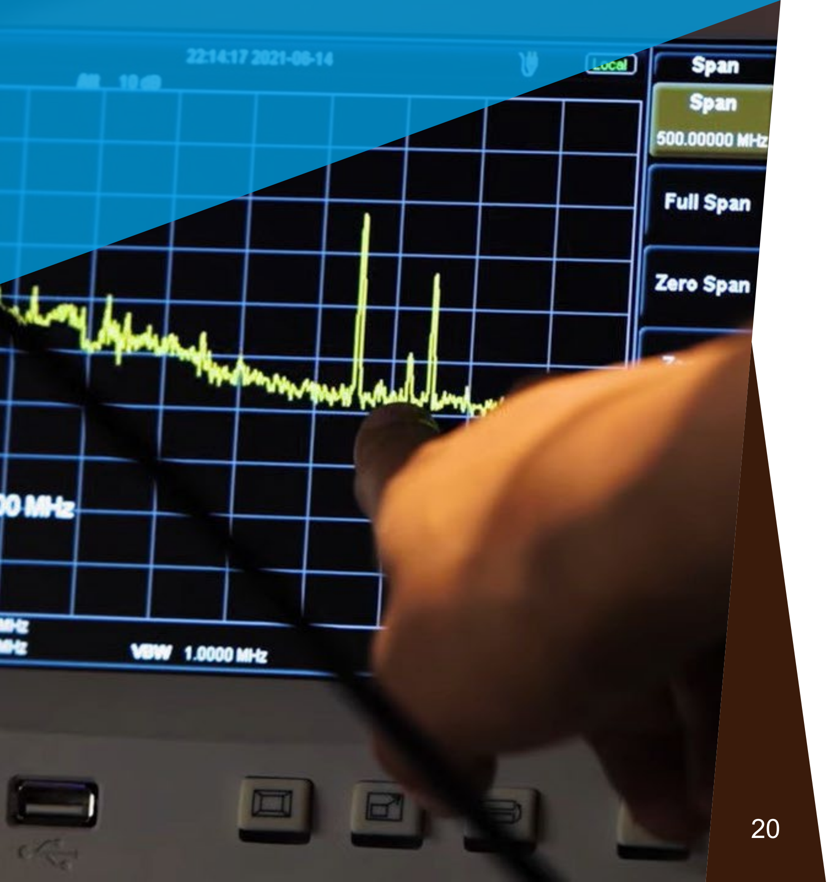

COURSE OVERVIEW
1st year – Spring semester (S8)

CORE COURSES – 6 ECTS

- Solid state physics and physics of materials (6 ECTS)

SPECIALIZATION COURSES – 6 ECTS

- Ultrafast optics and laser processing (3 ECTS)
- Physics of fluids and transport (3ECTS)
- Introduction to plasma physics (3ECTS)
- Molecular photonics (3ECTS)
- Neurophotonics (3ECTS)
- Oncophotonics (3ECTS)
- Introduction to physics of soft matter and complex systems (3ECTS)
- Optoelectronics (3ECTS)

Ligth, Matter and iNteractions

1st year - spring semester

Core courses

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Solid state physics and physics of materials

SEMICONDUCTOR BAND STRUCTURE

- Introduction. Crystal structures, Bloch functions and the Brillouin zone. Energy bands. Effective mass and density of states.
- Dynamic interpretation of Effective mass and the concept of holes. Carrier statistics in semiconductors.
- Intrinsic semiconductors. Doped semiconductors. Synchrotron radiation for Crystal structure and Energy band investigation.

ELECTRONIC PROPERTIES OF METALS AND SEMICONDUCTORS

- Introduction. Drude theory. Boltzmann's equation. Scattering mechanisms.
- Recombination. Transport equations in a semiconductor. The Hall effect.

CRYSTAL VIBRATIONS. PHONON.ELECTRON-PHONON COUPLING AND PHONON-PHONON COUPLING

- Vibration modes of mono atomic lattices. Optical phonons.
- Mechanism of electron-phonon coupling. Polaron.
- Polariton. Dispersion of electromagnetic waves in ionic crystal.

OPTICAL PROPERTIES OF SEMICONDUCTORS

- Dipolar elements in direct gap semiconductors.
- Absorption and spontaneous emission. Absorption threshold. Photoluminesence peak.
- Conditions for Optical amplification in semiconductors. Solid state lasers.
- Excitons. Absorption spectra of excitons.

LIGHT EMITTING DIODES AND LASER DIODES

- Surface phenomena. the p—n junction.
- Electroluminescent diodes: Electroluminescence; Internal and external efficiencies for LEDs.
- Characteristics of laser diode emission: Spectral distribution; Spatial distribution.

SUPERCONDUCTIVITY

- Basic phenomena and phenomenological London theory.
- Electrodynamics. Meissner effect.
- Electromagnetic Absorption of infra-red radiation.
- Abrikosov vortices.
- Superconducting bolometer and single-photon detectors.

MAGNETISM

- Quantum diamagnetism and paramagnetism.
- Magnetically ordered states and spin-wave excitations.
- Magneto-Optical phenomena. Faraday and Cotton-Mouton effects.
- Light induced magnetism. Magneto-Optical properties of semiconductors.
- Inverse Faraday effect and ultrafast magnetization reorientation.

Ligth, Matter and iNteractions

1st year - spring semester

Specialization courses

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Ultrafast optics and laser processing

- Principles of generation and amplification of ultra-short pulses.
- Description of their most common distortions in space and time and how to avoid them—or take advantage of them.
- Nonlinear optics of ultrashort pulses for converting pulses to almost any color.
- Additional interesting and potentially deleterious effects nonlinear optical processes can cause.
- Techniques for ultrashort-pulse measurement.

AVANCED IN SOLID-STATE ULTRAFAST LASERS
- Optically pumped lasers; Modes of a resonator; Pulsed operation, Q-switching; Mode-Locking.
- NLO and Kerr Lens Modelocking; Ultrafast Nonlinear Fibre Optics and pulse Propagation in Optical Fibres.
- Ultrafast fiber lasers; Ultrafast amplification.
- Chirped-Pulse Amplification; Other architectures; OPCPA; Phase stabilization.

DIAGNOSTICS OF ULTRAFAST LASERS
- General Considerations on pulse diagnostic; Intensity Autocorrelation.
- Spectrograms; Interferograms; Tomograms; SPIDER .

FEMTOSECOND LASER MICROMACHINING
- Interaction of femtosecond pulses with non transparent materials.
- Absorption; Relaxation dynamic; Ablation.
- Practical aspect of micromachining non transparent solid.
- Collateral damage and heat affected zone.
- Near Threshold ablation; Ablation efficiency; Polarization effect.
- Interaction of femtosecond pulses with transparent materials.
- Nonlinear absorption; Surface ablation; 3D localization; Nonlinear propagation.
- Practical aspect of micromachining transparent solid; Ablation and index change.
- Multiple pulse heat accumulation; Dome micromachining example.

Physics of fluids and transport

- Tensor formalism (strain, speed gradient), Navier-Stokes equation.
- Conservation equations: Mass, translation momenta, energy.
- Surface tension: microscopic description, Laplace law, phases contact, capillarity and gravity.
- Acoustic waves (Lagrange approach, Euler approach), surface waves (gravity, capillarity).
- Jeans instabilities.
- Transport (diffusion of particles, heat diffusion, viscosity): phenomenological approach, microscopic interpretation.

Introduction to plasma physics

Prerequisite to plasma and radiation physics, and radiation and laser initiated nuclear reactions.

- Characteristic quantities and properties of plasmas.
- Motion of charged particles in magnetic and electric fields.
- Bi-fluid description of plasmas and the eigen modes in magnetized and non-magnetized plasma.

Molecular Photonics

The course will involve a discussion of modern molecular organic photochemistry with emphasis on mechanisms.

The **first several lectures** will discuss the Fundamental Principles of Photochemistry (Chapters 1-3), in particular the fundamental paradigms of how light is absorbed by molecules and the photochemical and photophysical mechanisms by which molecules dispose of the excess energy acquired by light absorption will be reviewed.

Some quantitative examples of the photophysical radiative and radiationless processes (Chapters 5 and 6) will be reviewed.

The goal of these lectures will be the generation of paradigms for understanding rates and efficiencies of radiationless and radiative processes.

Following lectures will discuss

a) Electronic energy transfer (Chapter 9) and the two basic mechanisms of energy transfer (electron exchange and dipole-dipole mechanisms).
b) The paradigms for determining photochemical mechanisms (Chapter 8).
c) Theory of the fundamental photochemical primary processes (Chapter 7).
d) Examples of each of the important photochemical primary processes and synthetic applications of photochemical reactions (Chapters 10-13).

Neurophotonics

This course provides an in-depth survey of advanced optical microscopy techniques to measure, manipulate and follow molecular events in living neuronal cells. The neurobiological context needs to be introduced properly for the students to understand the scientific motivation and technological challenges of neurophotonics.

BRAIN FUNDAMENTALS 1: Introduction to neuroscience; brief history, present & future; brain development and neuroanatomy: macroscopic architecture, brain areas, cell types; molecular and cellular architecture; model systems / experimental preparations: dissociated cell culture, organotypic and acute brain slices, in vivo brain, brain organoids, disease model systems.

BRAIN FUNDAMENTALS 2: Neurophysiology and neurochemistry; excitability, action potential generation and propagation, synaptic transmission & plasticity; electrophysiology, intra- and extracellular recording of neuronal activity (*in vitro* and *in vivo*, patch-clamp, sharp electrode, MEA); ion-selective electrodes.

INTRODUCTION TO OPTICAL IMAGING: Optical properties of brain tissue, scattering and absorption, depth penetration, endogenous and exogenous contrast mechanisms, labeling, optical sectioning, spatial and temporal resolution, non-invasiveness, phototoxicity. Basics of optical imaging, fluorescence microscopy, OCT, CARS, photo-acoustic imaging, and more.

LASER-SCANNING FLUORESCENCE MICROSCOPY: Confocal and multi-photon microscopy, and other fluorescence techniques (FRET, FLIM, TIRF); Instrumentation technology, lasers, detectors and more.

OPTICAL ACTUATORS AND OPTICAL CONTROL OF NEURONS: Optogenetics tools for elucidating cortical circuit structure and function, chemogenetics, photolysis ('uncaging'), photobleaching and photoactivation techniques, from basic principles to *in vivo* applications.

CALCIUM AND VOLTAGE INDICATOR IMAGING in neurons, organic (synthetic) dyes and genetically encoded indicators, two-photon calcium imaging in axons and dendrites, two-photon calcium imaging of activity of large populations of neurons *in vivo.*

DESIGN AND PROPERTIES OF BIOSENSORS to image cellular physiology and molecular function, such as visualization of gene expression and protein synthesis in real-time, monitoring of protein trafficking, and other molecular events in in various neuronal compartments, including tracking of single receptors on membrane, and detecting extracellular glutamate (GluSnFR) and more.

IMAGE PROCESSING AND ANALYSIS FOR MICROSCOPY: Spatial filtering, deconvolution, segmentation, Deep Learning...

Oncophotonics

The course will provide a modern introduction to the relevant biological and technological topics:

- Cancer biology, tumor invasion, vascular biology, angiogenesis.
- In vitro, in vivo, in silico, organoid model systems.
- Photonics as a tool for cancer research, technology and applications (microscopy, bio-sensors, light-sensitive actuators etc).
- Photonics for clinical diagnostics and therapy "in the real world".
- Emerging concepts.

Introduction to physics of soft matter and complex systems

- Brownian movement.
- Interactions between colloids and nanoparticles.
- Interface and wetting.
- Polymers.
- Liquid Crystals.
- Surfactants and biomimicry systems.

Optoelectronics

Section 1 : Optical detection performance

1. OPTICAL DETECTION PERFORMANCES

- Noise detection.
- DIRECT and COHERENT detection : principle, performances, Signal to Noise Ratio (SNR).

2. OPTICAL AMPLIFICATION

- Erbium doped fiber amplifier: principle of operation; Noise Figure; Amplified transmission: noise accumulation.

3. PRE-AMPLIFIED OPTICAL DETECTION

- Optical Signal-to-Noise Ratio : SNR for DIRECT and COHERENT detection with pre-amplification.

Section 2 : Optical modulation techniques

1 . SEMI-CONDUCTOR DIODE LASERS

- Optically induced band-to-band transitions in semiconductors; Diode lasers : principle of operations; Examples; Direct-current modulation of semiconductor lasers.

2. ELECTROOPTIC EFFECT

- Linear electrooptic effect: Short reminder about properties of birefringent materials; Modification of the index ellipsoid under EO effects; Modification of the impermeability tensor coefficients by linear EO effect; Example : linear EO effect in KDP.
- Electrooptic modulation: Polarization modulators; Amplitude modulators; Phase modulators.
- Electrooptic modulator configurations: Longitudinal modulators; Transverse modulators; Integrated-optical modulators.
- Electrooptic effect in liquid crystals - Spatial modulators.

3. ACOUSTOOPTIC EFFECT

- Introduction to acoustooptic interaction.
- Photoelastic effect: Mechanical strain tensor; Strain-optic tensor.
- Bragg diffraction by an acoustooptic grating: Permittivity variation under elasto-optic effect; Acoustooptic Bragg diffraction.
- Acoustooptic modulators.

Light, Matter and iNteractions

COURSE OVERVIEW
2nd year – Fall semester (S9)

SPECIALIZATION COURSES – 6 ECTS

- Quantum Optics (3 ECTS)
- Light manipulation of matter (3ECTS)
- Advanced plasma physics (3ECTS) and radiative plasmas (3ECTS)
- Extreme light interaction and attosciences (3ECTS)
- Nanophysics (3ECTS)
- Optics of nanomaterials (3ECTS)
- Nano-opto-electro-mechanics (3ECTS)
- Advanced Statistical physics (3ECTS)
- Biophysics (3ETCS)

LABORATORY COURSES – 18 ECTS

- Laser-generated plasmas (9 ECTS)
- Biophotonics at Bordeaux Imaging Center & IINS (6ECTS)
- Nanophotonics at Basque Country (3 ECTS)
- Multiphysics simulations (6 ECTS)
- On-demande Laboratory research projects (3 ECTS)

Ligth, Matter and iNteractions

2nd year – fall semester

Specialization courses

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Quantum optics

- Phenomenological approaches to laser-matter interaction.
- Semi-classical approach: density matrix. Evolution in the presence of relaxation, pilot equation.
- Perturbative treatment and susceptibility.
- Quasi-resonant interaction in two-level systems.
- Optical Bloch equations. Coherent transients. Ultra-high resolution spectroscopy. Ramsey Fringes.
- Quantum description of the free electromagnetic field: Quantification of radiation, stationary states of radiation, coherent state. Spontaneous emission. Photon statistics.
- Interaction between a two-level system and a quantum field: Hamiltonian and interaction process. Dressed atom method.
- Photodetection signals.

Light manipulation of matter

LASER COOLING AND TRAPPING: COLD ATOMS

- Radiative forces.
- Slowing down, cooling, trapping atoms by lasers.
- Magnetic trapping and evaporative cooling, Bose-Einstein condensation.
- Applications: Metrology, Quantum Simulators.

OPTICAL TWEEZERS

- Structuration of matter by light.
- Interaction of structured light (vortex beams...) with structured matter.
- Light manipulation of vortex matter.

Advanced plasma physics and radiative plasmas

- Collective behavior of a fluid or a gas of charged particles in the presence of external and selfconsistent electric and magnetic fields.
- Main formalisms of the collective dynamics and particle kinetics described by the Vlasov and Fokker-Planck equations.
- Particle collision phenomena and their role in energy transport and wave damping.
- Interaction of radiation with matter: photo-ionization and the diffusion, absorption of the radiation and radiative cooling of the matter.
- Main mechanisms of laser interaction with plasmas: propagation and absorption of the laser and heating of the plasma.

Extreme light interactions and attosciences

At high intensity, the non-linear character of laser-plasma interaction is manifested by the importance taken by the radiation pressure and by the appearance of various "parametric“ instabilities likely to disturb the propagation of the laser radiation. At very high intensity, the relativistic effects appear, even the effects of quantum electrodynamics.

- Free electron in an ultra-intense wave.
- Relativistic index and induced transparency.
- Relativistic autofocusing.
- Relativistic ponderomotive force.
- Instabilities in the relativistic regime.
- Radiation Damping, Classical Models of Charged Particles.
- Radiation by charged particles.
- Effects of quantum electrodynamics.
- Acceleration of charged particles: wake of an intense laser pulse in a low density plasma and acceleration of electrons ; interaction with a dense target, Electronic heating and ion acceleration on the back.

- Attosecond Physics: Introduction and motivations
- Generation of high order harmonics and attosecond pulses.
- Temporal characterization of attosecond pulses.
- Harmonic spectroscopy.
- Application of attosecond pulses: measurement of delays to photoionization; attosecond transient absorption spectroscopy.
- Experimental tools: vacuum, XUV spectroscopy, particle spectroscopy.
- Theoretical tools: semi-classical modeling of attosecond physics.

Nanophysics

- What is **Nanophysics**? Introduction to the physical properties of nanosystems. « Top-Down » and « Down-Top » approaches.
- Electronic states and bands structures of nanoscale materials. 2D, 1D and quantum dots structures.
- Optical properties of nanoscale materials. Size-dependent optical properties and electromagnetic interactions.
- Nanoelectronics. Quantum transport, electron interference phenomena at nanoscale. Coulomb blockage and single electron transport.
- Quantum Hall effect in two dimensional electron gases.
- Graphene. Electronic band structure. Effective model at low energy (Dirac equation). Klein tunneling. Optical properties of graphene.
- Superconductivity at the nano-scale. Josephson junctions and superconducting nanoelectronics.
- Spintronics. Giant magnetoresistance. Magnetic moment manipulation via the electric current.

This lecture can be complemented by on-demand lab courses :

⇒ Magnetism and light interaction in solid state/ Light and magnetism in quantum materials.
⇒ Light and superconductivity.
⇒ Dirac materials and topological insulators.

Optics of nanomaterials

- Introduction to optical spectroscopy and photophysics of molecular systems.
- Metallic nanostructures: Optical properties of noble metals and plasmonic nanostructures, dielectric confinement, applications.
- Semiconductor nanostructures, quantum confinement, consequences of the density of states on the optical properties.
- Semiconductor quantum dots and colloidal nanocrystals: photophysics and applications.
- 1D quantum systems, Carbon nanotubes.
- 2D quantum materials.
- Single photon sources.

Nano-opto-electro-mechanics

NANOMECHANICS WITH PHOTONS AND ELECTRONS.

The lectures give introduction and foundations to the rapidly evolving field of nanomechanics.

Detection and actuation of nanomechanical systems is a challenge that is delivering already ultrasensitive quantum-limited detectors, quantum memories or buses, and answers to fundamental questions related to quantum decoherence.

We will introduce input-output formalism and describe opto-mechanical detection and cooling. Single-electron tunneling in presence of Coulomb Blockade will then be described. It is at the basis of the most advanced systems that take advantage of the coupling of superconducting Q-bits to microwave cavities.

Advanced statistical physics

The idea of this course is to give a general introduction to stochastic processes which will be useful in a wide variety of scientific areas for both pure and applied research.

Many processes in physics appear to behave randomly. The occurence of randomness is intrinsically linked to thermal or quantum fluctuations. For instance, a colloid in a liquid undergoes a continuous random motion known as Brownian motion which is the simplest form of a continuous time stochastic process. We will see how stochastic processes can be used to model a huge variety of processes from physics, chemistry and biology (and even economics where they are used to study stock market movements). The probability distributions of many stochastic processes obey the Fokker-Planck equation. This equation can be used to find the steady state distribution or other quantities such as survival probabilities. Discrete systems, for instance Ising spins or particles on a lattice, also have dynamics which can be described by Markov chain. Physically the systems evolution in the future only depends on its current state and not all of its past history. The idea of a Markov chain is vital for numerical simulation of discrete interacting systems, where we cannot compute the thermodynamic properties analytically, and is employed in Monte Carlo simulations.

1. STOCHASTIC CALCULUS AND LANGEVIN EQUATIONS

1.1. Discrete time continuous space stochastic processes.
1.2. The Ito Stochastic Calculus.
1.3. Examples of Stochastic Differential Equations - underdamped Brownian motion and taking the over damped limit.
1.4 The Generator and the Forward Fokker-Planck Equation.
1.5 Links with physical descriptions of diffusion, Fick's law.
1.6. First passage times.
1.7 Transport properties of a colloid in spatially varying potential.
1.8. Reduction of underdamped equations to over damped equation - the method of projection operators.
1.9 Stochastic processes in Fourier space - correlation functions.
1.10 Partially damped simple harmonic oscillator in the Langevin treatment, fluctuation dissipation theorem and Kramers Kronig Theorem.

2. MARKOV CHAINS

2.1 Basic definitions and applications.
2.2 Master equations for Markov chains.
2.3 Detailed balance and the principle of Monte Carlo simulations for equilibrium statistical physics systems, sampling questions for Monte Carlo simulations.
2.4 Glauber solution for the dynamics of 1D-Ising Model.
2.5 Correlation and response functions for Markov chains - generalised proof of fluctuation dissipation theorem - applications, for example conductivity of metals.

Biophysics

- Biological membranes.
- Liposomes and red blood cells: mechanical behavior.
- Mobility of membrane proteins and lipids.
- Intracellular traffic.
- Adhesion.
- Cell Junctions.
- Thermodynamic and kinetic approaches.
- Cellular mechanics.
- Cellular rheology: Architecture and passive mechanical properties.
- Active processes: spreading, traction, migration, cell motility.
- Signage.
- Electrical impulses in the cells.

Ligth, Matter and iNteractions

2nd year - fall semester

Laboratory courses

université de BORDEAUX

Laser-generated plasmas

This training includes a four-week national gathering of Master students in Bordeaux for experimental sessions on high power lasers and laser plasma interaction, as well as numerical sessions on simulations of laser plasma interaction.

The evaluation consists in oral presentations and oral examinations.

Biophotonics at Bordeaux Imaging Center and IINS

This training takes place at the Bordeaux Imaging Center and IINS.

General and practical lectures are given by researchers on bio-imaging techniques and data analysis. Then, pairs or trinomials of students with various backgrounds (physics, chemistry, biology) are given a project to discover an advanced biophotonics imaging technique. The evaluation is based on a written report.

Nanophotonics at Fotonika (Basque Country)

This training takes place at several partner universities (San Sebastian, Bilbao) from Fotonika (Euskampus photonics community: https://www.fotonika.eus/en) and consists in trainings in advanced nanophotonics, plasmonics and optical spectroscopy techniques.

The evaluation is based on the basis of a short (8 pages) report formatted as a lecture, an oral presentation (15 minutes) and questions of the pedagogical team.

Multiphysics simulations

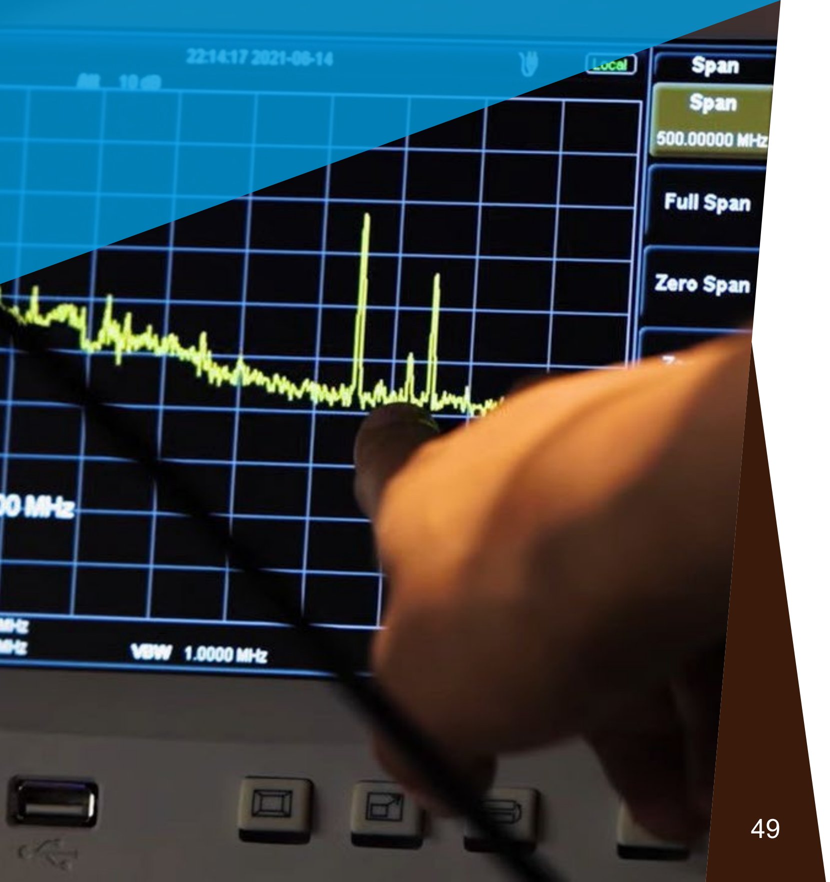
This training proposed by IOGS consists in Multiphysics simulation projects related to laser physics, nanophotonics and cold atoms. They are performed at the Institut d'Optique d'Aquitaine using IOGS's computing resources. The evaluation consists in three reports (one for each project).

On-demand Laboratory research project

Before the work begins, a syllabus of the work program is developed by the student and has to be submitted to the pedagogical team of the Master for validation. A significant part has to be devoted to bibliography. A lab course may lead to an internship but is NOT a short internship. The students have regular meetings with the researchers but are not hosted by their laboratory. The evaluation is based on the basis of a short (8 pages) report formatted as a lecture, an oral presentation (15 minutes) and questions of the pedagogical team.

These courses are proposed by researchers from the Bordeaux Campus and aim at "hands-on" learning of a research topic in a research laboratory environment, which may be experimental, theoretical or numerical.

Light, Matter and iNteractions



COURSE OVERVIEW
2nd year – Spring semester (S10)

MASTER THESIS / INTERNSHIP – 30 ECTS

Research work on a given topic. Students must carry out research on a given topic under the supervision of a university staff member. They are in charge of writing a report synthesizing the approach, method and results associated with the work including their critical analysis.

LIGHT Sciences and Technologies

Physical chemistry and Chemical physics

Pr. Véronique Jubera & Pr. Frédéric Castet– Academic coordinators

université de BORDEAUX

Physical chemistry and Chemical physics

COURSE OVERVIEW
1st year – Fall semester (S7)

CORE COURSES – 12 ECTS
- Statistical Thermodynamics 1 (6 ECTS)
- Quantum Mechanics (6 ECTS)

SPECIALIZATION COURSES – 12 ECTS
- Numerical methods (6ECTS)
- Elective (6ECTS)

PRACTICUM COURSES – 6 ECTS
- High resolution atomic spectroscopy
- Lasers and nonlinear optics
- Optical materials: Luminescent and X-Chromic materials

Physical-Chemistry & Chemical-Physics

1st year - fall semester

Core courses

université de BORDEAUX

Statistical Thermodynamics 1

The objectives of the course are to explain the macroscopic behavior of systems through their microscopic description, and to present the universal characteristics in the study of thermodynamic systems.

STATISTICAL THERMODYNAMICS

1. Reminders of thermodynamics.
2. A more general approach to statistical thermodynamics.
3. Generalities on systems of identical particles without interaction.
4. Applications of Boltzmann statistics.
5. An example of the use of another statistic: blackbody radiation.

PHASE TRANSITIONS

1. Background :

- The regular solution model and its consequences.
- Some experimental results from magnetism, magnetic order, the ferromagnetic example.

2. The para-ferromagnetic transition :

- Ising's model, phase diagram in the mean-field approximation, link with the regular solutions model.
- The vicinity of the Curie point.

3. Introduction to Landau theory:

- What is spontaneous symmetry breaking, a simple example of mechanics;
- Symmetry breaking associated with the para-ferromagnetic transition, associated order parameter. Introduction to Landau expansion.
- Generalization, other types of development, weak first-order transitions.
- Some examples from liquid crystals.

Quantum mechanics

Objectives:

LEARNING THE DISCIPLINARY FUNDAMENTALS

- Postulates and representation of quantum states.
- Hilbert spaces and quantum superpositions.
- Operators and the principle of measurement.
- Schrödinger equations and the notion of CSCO.
- Symmetries in quantum mechanics.

LEARNING TRANSFERABLE SKILLS

- Approximation methods: Variations, perturbations and variation-perturbation methods.
- Constrained optimization.
- Time-dependent perturbation theory.
- Linear response theory.

RELATED LEARNING – APPLICATIONS

- Microphysical electrical and magnetic properties.
- Multipole moments of a charge distribution - Interaction energy with a static electric field.
- Charge fluctuations and electronic transport.
- Magnetic fluctuations of an effective electron spin system.
- Fundamentals of matter-radiation interaction (optical processes).

Physical-Chemistry & Chemical-Physics

1st year - fall semester

Specilization courses

université de BORDEAUX

Numerical Methods

LEARNING OF NUMERICAL TOOLS

- Analysis and representation of data.
- Graphical tools.
- Numerical analysis and scientific programming for the treatment of problems belonging to physics and chemistry.

Elective 1/3: Inorganic Materials

This course is devoted to the development of inorganic materials. A first part deals with the extraction of minerals and large metallurgical processes. The second part develops the different methods for the synthesis of inorganic materials in powder form. An introduction to sintering is also presented. A focus is carried out in a third part on the innovative ways of sol-gel type chemistry. In a last part thin-film processes are exposed.

Teaching program

TRANSFORMATION PROCESSES IN INORGANIC CHEMISTRY

- Bayer process: aluminum oxide (alumina) and aluminum chemistry.
- Kroll process: rutile and titanium chemistry.
- Silicon transformation and purification processes: obtaining silicon for organic chemistry, photovoltaics and electronics.

SYNTHESIS AND FORMULATION OF INORGANIC POWDERS

- Dry routes for preparing oxides: solid-phase routes (Chamotte-Broyage), mechanosynthesis.
- Solution routes for oxide preparation: autocombustion, spray pyrolysis, Sol-Gel Pechini and alkoxide route, precipitation and co-precipitation, hydrothermal synthesis.
- From oxides to other inorganic compounds.

SOL-GEL AND DISPERSED MEDIA

- From hard colloids to the sol-gel process.
- Colloids and particle soils "non-silicates.
- "Silicate" colloids and particle soils.

FROM SYNTHESIS TO MATERIALS DEVELOPMENT

- Forming processes by dry routes (PVD-CVD), ion implantation, thermal spraying and diffusion (heat treatments).

Elective 2/3: Structural Analysis

From a description of the light-matter interactions, the main classes of physical and chemical characterization will be described. In the case of the characterization of surfaces, students should know more particularly certain techniques of spectroscopy (photoelectrons, Auger, X-ray fluorescence) or electron microscopy (transmission and scanning). For the structural analysis of the crystallized solids the student should be able initially to describe their periodic structure using groups of space and the international tables of crystallography. The study of powder and single crystal X-ray diffraction will allow student to determine the space group that describes the symmetry of the studied object and connect the intensities measured to the positions of the atoms in the unit cell.

Elective 3/3: Theory of chemical bond

Through the study of chemical bonding, the aim of this course is to enable students to link structure/composition and reactivity/properties of compounds, whether organic molecules, transition metal complexes or compounds derived from solid state chemistry. Particular emphasis will be placed on reactivity in organic chemistry (Woodward-Hoffmann rules, electrocyclic reactions, sigmatropic transpositions, etc.); properties of transition metal complexes (Tanabe-Sugano diagrams, Marcus law, Curie law) and properties of solids (ionic models, band theory, etc.).

Physical-Chemistry & Chemical-Physics

1st year - fall semester

Practicum courses

université de BORDEAUX

High resolution atomic spectroscopy

- Single-mode tunable laser (diode laser).
- Absorption spectrum of an atomic vapor (Cesium atoms).
- Inhomogeneous broadening due to Doppler effect at room temperature.
- Emission spectrum of atomic vapors.
- Saturated absorption spectroscopy of atomic vapors.
- Measurement of the homogeneous linewidth of electronic transitions.
- Zeeman effect, Faraday effect.

Lasers and nonlinear optics

INTRODUCTION SESSION TO BASICS OF OPTICS

- Gaussian beams.
- Optical resonators.
- Laser cavities.
- Nonlinear optics.
- Parametric cavities and nonlinear gain.

PRACTICUM#1 – OPTICAL RESONATORS AND SECOND HARMONIC GENERATIONS

- Basics of laser cavities: the Helium – Neon laser.
- Laser amplification.
- Passive cavities: the case of Fabry-Perot etalon.
- Second harmonic generation: an insight in non-linear optics.

PRACTICUM#2 – DIODE-PUMPED Nd:YAG LASER CAVITY

- Diode pump characterization.
- Laser cavity stability, resonant laser mode and mode-matching.
- Laser slope: laser threshold and laser efficiency.
- Intra-cavity second harmonic generation.

PRACTICUM#3 – OPTICAL PARAMETRIC OSCILLATOR (OPO)

- Parametric cavity stability, resonant parametric mode and mode-matching.
- Phase-matching characterization and polarization dependence.
- Non-linear slope: parametric threshold and parametric efficiency.
- Application of the pulsed beams to time-resolved spectroscopy.

FINAL SESSIONS – MODELLING OF SOME ASPECTS (DEPENDING ON MEASURED DATA)

- Geometry of resonant laser and/or parametric Gaussiand beams.
- Angular spectral acceptance of second harmonic generation.
- Emission threshold and gain efficiency (laser and/or parametric cavity).
- Rare-earth lifetime.

Optical materials: Luminescent and X-Chromic materials

Synthesis and metrology of luminescent glasses and piezo-chromic materials.

PRACTICUM #1 –EMITTING COMPOUNDS

- Synthesis of a RE doped glass.
- Characterizations: XRD, density, transmission, refractive index and RE luminescence.
- Heat treatment of the glass: evolution of the XRD pattern and emission properties.

PRACTICUM #2 –COLORED PIGMENTS WITH X-CHROMIC PROPERTIES

- Synthesis of Cu(Mo,W)O4 compounds (at least 3 Mo/W ratios).
- Characterizations:
  → XRD (High and Low T° forms both stable at room T°).
  → A phase transition versus temperature (Kofler Bench).
  → A phase transition versus pressure (uniaxial press).
  → A phase transition versus Ph.
  → Dependency versus Mo/W ratio.
  → Colorimetric parameters (RGB, XYZ, Lab spaces).
- Discussion on the Kinetic of the phase transition.

Physical chemistry and Chemical physics

COURSE OVERVIEW
1st year – Sping semester (S8)

CORE COURSES – 6 ECTS
– Solid State Physics (6ECTS)

SPECIALIZATION COURSES – 12 ECTS
– Quantum Chemistry & Molecular modelling (6ECTS)
– Spectroscopy (6ECTS)

INTERNSHIP – 12ECTS

Physical-Chemistry & Chemical-Physics

1st year - spring semester

Core courses

université de BORDEAUX

Solid State Physics

This lecture provides an introduction to the physics of the solid state. The objectives are: (i) the description of the lattice vibrations (phonons) as well as (ii) the electronic structure of different types of solids: metals, semimetals, semi-conductors, and insulators. Different levels of description and basic concepts are discussed: the free electron gas model, concept of reciprocal lattice, Bloch theorem, quasi-free electron model, tight-binding model, electronic bands theory, thermal and conduction properties.

CONTENT:

Lectures

- Elementary classical and quantum aspects of the free electron theory of metals.
- Electrons in a weak periodic potential: Bloch's Theorem, perturbation theory applied to periodic potentials, band structure, Fermi surfaces and Brillouin zones, nearly free electrons model.
- General properties of semiconductors.
- The Tight-Binding model, a chemist's view of bonding in solids.
- Phonons and lattice vibrations: classical and quantum theories of the Harmonic crystals, normal modes, elementary theory of the phonon dispersion relation, electron-phonon interaction.
- Electromagnetism in matter: Maxwell's equations, polarization, dielectric constant, the propagation equation, reflectance, transmittance and absorption, dielectric, metals and semiconductors, blackbody radiation.
- Optical properties of metals.
- Optical properties of nanoparticles.
- Photonic applications: sensors, LED's, quantum dots, solid state lasers, spectroscopy, photonic crystals.

Practicals

- Computational procedure for the study of periodic systems.
- Energy minimization and ground-state properties calculations.
- Structural optimization, Lattice relaxation.
- Calculation of density of states and bands diagrams.

Physical-Chemistry & Chemical-Physics

1st year - spring semester

Specilization courses

université de BORDEAUX

Quantum Chemistry & Molecular Modeling

Program

Understanding the concepts of quantum chemistry at the appropriate level to undertake molecular modeling. Determination of geometries, electronic and optical properties of organic molecules using Quantum Chemistry software. Simulation of reaction processes using Quantum Chemistry software.

INTRODUCTION

- Polyelectronic wave function architectures: orbital models.
- Mono- and multi-configuration descriptions.
- Spin states, valence bond models and molecular orbital models.
- Orbital basis developments: ab initio and semi-empirical models.

THE HARTREE-FOCK MODEL: FOUNDATIONS, USES AND LIMITATIONS

- Application: SCF-LCAO calculation of the electronic ground state of the helium atom (use of numerical tools).

GAUSSIAN ATOMIC FUNCTION BASES (POPLE, DUNNING)

SEMI-EMPIRICAL MODELS

- Application: Electronic structure of the LiH molecule (classical TD and use of AMPAC code).
- Application: Electronic structure of pi-conjugated organic molecules: electron density analysis, inductive and mesomeric effects, atomic partial charges, bond indices, resonance structures (use of AMPAC code).

ELECTRONIC CORRELATION – VARIATIONAL METHODS: CONFIGURATION INTERACTION AND MULTICONFIGURATION METHODS

- Application: IC calculation of the electronic states of the hydrogen molecule (classical TD and use of the AMPAC code).
- Application: Excited states of the LiH molecule (classical tutorial and use of AMPAC code).
- Application: Simulation of electronic transitions in pi-conjugated organic molecules (using AMPAC code).
- Application: Energy profile of hydrogen molecule dissociation: HF / VB / CI comparison (using Gaussian code).

Spectroscopy

Objectives

- Understanding the fundamentals of light-matter interaction, molecular optical spectroscopy (electronic transitions and molecular vibrations).
- Analysis and interpret of the spectra in the infrared and near-infrared.
- Analysis and interpretation of the Vibrational Spectra in Raman scattering.
- Analysis techniques of IR specular reflection (internal and external) and diffuse reflection.
- Acquire knowledge and master common vibrational techniques for analyzing the mass materials, thin films, interfaces, etc.
- Optical constants in materials.
- Acquired skills: mastering the techniques of IR spectroscopy and scattering Raman and understanding the spectra obtained.

Physical-Chemistry & Chemical-Physics

1st year - spring semester

Internship

université de BORDEAUX

Research Internship

Research project within a research group in a research laboratory of Bordeaux. These projects include a 2-month full-time internship (January-February), followed by a half-time internship from March to June.

Research departments

https://www.u-bordeaux.fr/en/research/research-organisation/research-units#titre_2

Physical chemistry and Chemical physics

COURSE OVERVIEW
2nd year – Fall semester (S9)

SPECIALIZATION COURSES – 12 ECTS

- Kinetics Statistical Thermodynamics 2 (6 ECTS)
- Photonics, lasers and imaging (6 ECTS)

LABORATORY COURSES –18 ECTS

- Computational chemistry & Molecular simulation (6 ECTS)
- Electives (12 ECTS)

Physical-Chemistry & Chemical-Physics

2nd year - fall semester

Specilization courses

université de BORDEAUX

Kinetics & Statistical Thermodynamics 2

KINETICS: this lecture brings together the issues of kinetics, its theoretical foundations and experimental approaches.

STATISTICAL THERMODYNAMICS: this lecture introduces concepts and methods of statistical thermodynamics for nonuniform or time dependent systems.

Based on the *Statistical Thermodynamics 1* course in the 1st year fall semester, this course aims to apply the concepts and methods of statistical thermodynamics to the case of non-uniform or non-equilibrium systems.

Situations of interest include:

- Continuous (sedimentation, ionic double layer) or discontinuous (phase separation) stationary composition profiles. Notion of correlation length.
- Kinetic description of a stationary (continuous) profile: Einstein relation.
- Growth mechanisms during phase separation. The metastable case ("nucleation") and the unstable case ("spinodal decomposition").

Photonics, lasers and imaging

This course deals with the Photonics field based on spectroscopic characterization of objects, molecules and materials with optical properties. It introduces the laser as a source but also as a tool for creating or modifying these properties. The notion of imagery is exposed through micro-Raman, nano-Raman characterization or micro-luminescence for mapping these objects.

Part 1 – QUADRATIC NONLINEAR OPTICAL PROPERTIES: FROM MOLECULES TO INTERFACES AND MATERIALS (VINCENT RODRIGUEZ)

1/ Optical Spectroscopies.

- Linear optical phenomena.
- Nonlinear optical phenomena.

2/ Quadratic Nonlinear Optics and Molecules.

- Hyper-Rayleigh Scattering (HRS).
- Some prototypical NLO dyes.
- A unique tool to elucidate the (Nano) Structure of materials .

3/ Second Harmonic Imaging in materials.

Part 2 – FROM MICROSCALE TO NANOSCALE CHEMICAL CHARACTERIZATION AND IMAGING

1/ Resonance Raman spectroscopy (including spontaneous and resonance Raman scattering, notions on fluorescence, applications to carbon materials and dyes).

2/ Molecular plasmonics (including notions on surface plasmons, optical properties of metal nanoparticles and surface-enhanced Raman spectroscopy (SERS) with various applications).

3/ Scanning Near-field Optical Microscopy (SNOM) (including generalities on far-field and near-field microscopy, scanning probe microscopies and the specific case of Tip-Enhanced Raman Spectroscopy (TERS) with applications in materials science and biology).

Part 3 – LUMINESCENCE SPECTROSCOPY AND IMAGING APPLIED TO INORGANIC MATERIALS (VÉRONIQUE JUBERA)

General introduction.

1/ Tools to explain luminescence spectroscopy.

2/ Luminescence properties of doped materials.

3/Imaging: Correlative microscopy.

4/ Applications of luminescent materials.

Physical-Chemistry & Chemical-Physics

2nd year - fall semester

Laboratory courses

université de BORDEAUX

Computanional Chemistry/ Molecular simulation

Numerical simulation is a science that strengthens the theoretical and experimental approaches. In chemistry, these methods are an important tool for the study, at a microscopic level, of systems ranging from the isolated molecule to liquids, solutions, polymers, materials, biological system, etc. The purpose of this course is to provide an overview of the concepts behind this scientific approach and present capabilities and limitations of the various methods of molecular simulation. This course should allow all students in chemistry to become familiar with molecular simulation and better understand the microscopic basics by atomic description of the interactions of a set of particles, the physical and chemical properties of the material.

CONTENT

This course consists of both theoretical lectures and practical computer exercises.

Basic concepts

- Elementary classical statistical mechanics. Ensembles and fluctuations
- Molecular interactions
- Molecular mechanics
- Equilibrium molecular dynamics simulations
- Monte Carlo methods
- Calculations of properties

Advanced methods

- Overview of various software.
- Methods of energy minimization.
- Free energy calculations.
- Computer graphics visualization.
- Elaborated interaction models.
- Ewald sum and reaction field methods for treating long-range electrostatic interactions.

The ability to use a powerful computational environment (computers, softwares, data handling) is central in this field. The lectures will link the standard molecular simulation methods together with their corresponding algorithms. Experiences in computer programming and in informatic languages are not prerequisites for this course but would be used if existed.

Elective 1/5: Large Scale Facilities

This course aims to introduce the contributions of large scale instruments (X synchrotron and neutron source), both at a fundamental and more applied level in the study of the structural and dynamic properties of the materials. This course teaching will give students a certain basis for PhD work using this kind of large instrument.

Elective 2/5: Dielectric and magnetic properties

This lecture aims to teach the basics on the dielectric and magnetic properties of inorganic and molecular materials. The purpose is to be able to describe, for a known structure material, the dielectric and magnetic properties and to know how to analyze them with the appropriate model.

Elective 3/5: Hybrid and nanomaterials

General overview concerning the use of the Tools of molecular, macromolecular, sol-gel chemistries and physico-chemistry to elaborate nanomaterials, control the organization and the properties of self-assembled macromolecular structures and of organic/inorganic hybrid materials.

- To know the main fabrication processes of inorganic nanomaterials (quantum dots, metals, metal oxide);
- To be able to describe the basics, fundamental chemistry and physics of nanosystems;
- To know the basis of block copolymer self-assembly at the bulk state;
- To know the main properties and applications of block copolymer-based materials as well as the main techniques to characterize them;
- To manipulate simple physico-chemical concepts to describe functional hybrid materials;
- To know the main classes and applications of hybrid materials;
- To be able to propose different synthetic strategies towards functional hybrid materials.

Elective 4/5: Laboratory course – Chemistry lab

These courses are proposed by researchers from the Bordeaux Campus and aim at "hands-on" learning of a research topic in a research laboratory environment, which may be experimental (synthesis, characterization, shaping of optical materials), theoretical or numerical.

Before the work begins, a syllabus of the work program is developed by the students in collaboration with a research group and has to be submitted to the pedagogical team of the Master for validation. A significant part has to be devoted to bibliography. A lab course may lead to an internship but is NOT a short internship. The student will follow PhD and postdoc subject to complete his work program. They will have to spend 24 or 48 hours dedicated to the discovery of technics, in the lab. The students have regular meetings with the researchers but are not hosted by their laboratory (visitors status). The evaluation is based on the basis of a short (10 pages) report formatted as a lecture or "*Technique de l'ingénieur*") and oral session of questions (30 minutes) of the pedagogical team.

Elective 5/5: Laboratory course – Fabrication and characterization of photonics materials

General and practical lectures are given by researchers on synthesis and fabrication, characterization and chemical analysis techniques and data analysis. Then, pairs or trinomials of students with various backgrounds (physics, chemistry, biology) are given a project to explore micro-to nanoscale objects with different optical functions. The evaluation is based on a written report.

This training takes place at state-of-the-art plateforms of the Bordeaux Campus:

– **Placamat**: https://www.placamat.cnrs.fr: materials for lighting shaped by SLS (additive manufacturing)
The laboratory course will provide students the opportunity to be exposed to inorganic material characterizations in the frame of additive manufacturing of luminescent composites for lighting applications. These objects will be shaping by SLS technic. The characterizations will be provided by the Placamat platform (TOF-SIMS, Tomography, MEB).

– **Bordeaux Imaging Center**: https://www.bic.u-bordeaux.fr/): depending on compatibility with the training schedule.

Physical chemistry and Chemical physics

COURSE OVERVIEW
2nd year – Spring semester (S10)

MASTER THESIS / INTERNSHIP – 30 ECTS

Research work on a given topic. Students must carry out research on a given topic under the supervision of a university staff member. They are in charge of writing a report synthesizing the approach, method and results associated with the work including their critical analysis.

LIGHT Sciences and Technologies

Biophotonics and neurotechnologies

Pr. Valentin Nägerl– Academic coordinator

université de BORDEAUX

Biophotonics and neurotechnologies

Available soon

For more information

Contact us at:
contact.light-st@u-bordeaux.fr

https://doctorat.u-bordeaux.fr/en/before-phd/graduate-programs/light-S-T

https://fr.linkedin.com/company/light-sciences-and-technologies-graduate-program

https://youtu.be/4J4Oj07ksgw