Graduate Research School

université de BORDEAUX

LIGHT Sciences and Technologies

Light, Matter and iNteractions

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Light, Matter and iNteractions

1st year – Fall semester (S7)

PREPARATORY COUSES – 12 ECTS

- Statistical Physics and Thermodynamics (6 ECTS)
- Electrodynamics (3ECTS)
- Lab programming (3ECTS)
- Optical microscopy (3 ECTS)

CORE COURSES – 12 ECTS

- Advanced quantum mechanics & light-matter interaction (6 ECTS)
- Laser Physics and Nonlinear Optics (3 + 3 ECTS)

PRACTICUM COURSES – 6 ECTS

- High resolution atomic spectroscopy
- Lasers and nonlinear optics
- Quantum sensing

All three have to be taken

Ligth, Matter and iNteractions

1st year - fall semester

Preparatory courses

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Statistical Physics and Thermodynamics

MICRO CANONICAL ENSEMBLE
- Statistical entropy
- 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
- Phase diagrams
- Clausius-Clapeyron formula
- Vapor pressure

INTERACTING SYSTEMS
- Classical particles
- Models on networks – Ising

APPROXIMATION OF AVERAGE FIELDS
- Variational 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

Electrodynamics 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.

3. Accelerated 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 a wave packet in a 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.

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
Basics of light-matter interaction: Absorption and Scattering (Mie, Rayleigh).
Contrast mechanisms in white light microscopy
Koehler illumination and bright field microscopy; Dark field microscopy; Strioscopy and Phase contrast microscopy
Differential interference microscopy
Quantitative Phase Imaging
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.
Adaptive optics in microscopy
Fluorescence lifetime imaging microscopy. Time correlated single 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

Ligth, Matter and iNteractions

1st year - fall semester

Core courses

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

- Introduction 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 effects
  - 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 – Introduction to basics of optics
▶ Gaussian beams
▶ Optical resonators
▶ Laser cavities and laser gain
▶ Nonlinear optics
▶ Parametric cavities and nonlinear gain
Practicum #1 – Optical resonators and second harmonic generation
▶ Basics of laser cavities: the Helium-Neon laser
▶ Laser amplification
▶ Passive cavities: the case of Fabry-Perot etalon
▶ Second harmonic generation: an insight in nonlinear 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
▶ Nonlinear slope: parametric threshold and parametric efficiency
▶ Application of the pulsed beams to time-resolved spectroscopy
Final session – Modelling of some aspects (depending on measured data)
▶ Geometry of resonant laser and/or parametric Gaussian 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

Light, Matter and iNteractions

1st year – Spring semester (S8)

CORE COURSES – 6 ECTS

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

SPECIALIZATION COURSES – 12 ECTS

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

Ligth, Matter and iNteractions

1st year - spring semester

Core courses

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 photon-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

Advances 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).

Introduction to physics of soft matter and complex systems

– Brownian movement
– Interactions between colloids and nanoparticles
– Interface and wetting
– Polymers
– Liquid Crystals
– Surfactants and biomimetic 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
a – 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
b - Electrooptic modulation
Polarization modulators; Amplitude modulators; Phase modulators
c - Electrooptic modulator configurations
Longitudinal modulators; Transverse modulators; Integrated-optical modulators
d - Electrooptic effect in liquid crystals - Spatial modulators
3 – ACOUSTOOPTIC EFFECT
a - Introduction to acoustooptic interaction
b - Photoelastic effect
Mechanical strain tensor; Strain-optic tensor
c - Bragg diffraction by an acoustooptic grating
Permittivity variation under elasto-optic effect; Acoustooptic Bragg diffraction
d - Acoustooptic modulators

Light, Matter and iNteractions

2nd year – Fall semester (S9)

SPECIALIZATION COURSES – 6 ECTS

- Quantum Optics (3 ECTS)
- Light manipulation of matter (3 ECTS)
- Advanced plasma physics and radiative plasmas (6 ECTS)
- Extreme light interaction and attosciences (3 ECTS)
- Nanophysics (3ECTS)
- Optics of nanomaterials (3 ECTS)
- Quantum Nanomechanics with Photons and Electrons (3 ECTS)
- Advanced Statistical physics (3 ECTS)
- Biophysics (3 ETCS)

LABCOURSES – 18 ECTS

- Laser-generated plasmas (9 ECTS)
- « CESTA » (6 ECTS): visit of laser MJ + gain simulations at CELIA
- Biophotonics at LP2N, Bordeaux Imaging Center & IINS (6 ECTS)
- Nanophotonics at Basque Country (6 ECTS)
- Multiphysics simulations (6 ECTS)
- On-demande Laboratory research projects (3 ECTS)

2nd year – Spring semester (S10)

MASTER THESIS – 30 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.

Quantum nanomechanics with electrons and photons

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

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.

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.

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

Lab courses

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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.

Common classes (all students):

Plasma diagnostics
Introduction to plasma diagnostics, Design and operating constraint on the LMJ or NIF facilities, Focus on LMJ PETAL, Observables to be measured in ICF and different diagnostic classes, X-ray diagnostics: imaging, spectrometry, Visible diagnostics: backscattered light, VISAR, Nuclear diagnostics

Intense lasers
Intense lasers: Nonlinear effects in laser chains, Laser chains: Notions of CPA, stretching and compression, Laser chains: Diagnostics

EXP Laser
Stretching and compression, Regenerative amplification, Wave surface analysis

EXP Plasma
Laser breakdown on solid target and in the air, Laser absorption in plasma, Hydrodynamic expansion of a laser plasma, Pump-probe manipulation principle, Imaging and spatial filtering of fast phenomena, Mach-Zehnder interferometry

PIC simulations
Introduction to Particle-In-Cell codes, Introduction to SMILEI, Choice of a project: Two-beam instability, Stimulated Raman Scattering, Plasma expansion in vacuum, Laser electron acceleration, Laser ion acceleration

Option ICF: Inertial confinement fusion, hydrodynamic simulations
Option UHI: Relativistic laser-plasma interactions, Extra EXP plasma, Extra PIC simulations

Biophotonics at LP2N, Bordeaux Imaging Center and IINES

General and practical lectures are given by researchers on bio-imaging techniques and data analysis. Then, pairs of students are given a project to discover an advanced biophotonics imaging technique. The evaluation is based on a written report and an oral presentation.

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, quantum optics 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

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.

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.