LIGHT Sciences and Technologies

Light, Matter and iNteractions
1st year – Fall semester (S7)

PREPARATORY COURSES – 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
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.
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
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, saturation. 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
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 AntiStokess 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)
Light, Matter and Interactions

1st year - fall semester

Practicum courses
High resolution atomic spectroscopy

- 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
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)
Light, Matter and Interactions

1st year - spring semester

Core courses
Semiconductor band structure

Electronic properties of metals and semiconductors

Crystal vibrations. Phonon. Electron-phonon coupling and photon-phonon coupling

Optical properties of semiconductors

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

Magnetism
Light, Matter and Interactions

1st year - spring semester

Specialization courses
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.
Introduction to plasma physics

*Prerequisite to advanced plasma physics and laser-generated plasmas.*

- 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
   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
SPECIALIZATION COURSES – 12 ECTS
- Quantum Optics (3 ECTS)
- Light manipulation of matter (3ECTS)
- Advanced plasma physics & radiative plasmas (3+3ECTS)
- Extreme light interaction and attosciences (3ECTS)
- Nanophysics (3ECTS)
- Optics of nanomaterials (3ECTS)
- Nano-opto-electro-mechanics (3ECTS)
- Advanced Statistical physics (3ECTS)
- Biophysics (3ETCS)

LABCOURSES – 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)

2nd year – Spring semester (S10)

MASTER THESIS – 30 ECTS
Ligth, Matter and iNteractions

2nd year - fall semester

Specialization courses
Quantum optics

- Phenomenological approaches to laser-matter interaction.
- Perturbative treatment and susceptibility.
- Quasi-resonant interaction in two-level systems.
- 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.
- Quantum Hall effect in two dimensional electron gases.
- 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

Many processes in physics appear to behave randomly. The occurrence 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 Itô 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
Laser-generated plasmas

Lasers, magnetohydrodynamics, scaling laws and laboratory astrophysics

In addition to this, this lab-course 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:

Lectures on intense lasers, practical training on lasers and plasmas, simulations
Options: - Inertial confinement fusion; hydrodynamic simulations
- Relativistic laser-plasma interaction, extra practical training on plasma and simulations
Biophotonics at Bordeaux Imaging Center and IINES

This training takes place at the Bordeaux Imaging Center and IINES

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

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.