SEMESTER 1

Preparatory courses – 12 ECTS

Statistical physics and thermodynamics (3+3 ECTS)

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 (3 ECTS)

1. Electrodynamics of vacuum
• Maxwell equations for potentials, Lorentz transformations for potentials and fields.
• Relativistic mechanics, quadrivectors, vector and scalar potentials, charge and current densities, ….

2. 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.

4. 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.

5. 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 (3 ECTS)

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

-Introduction to Labview
- o General presentation of Labview: why Labview
- o Data acquisition
- o Instrument control

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

-Introduction to Python
- o General presentation of Python. Why Python
- o Basic structure of algorithms

- o Image processing
- o Analysis tools
- o Plotting data

Introduction to Cell biology (3 ECTS)

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:
  - o protein synthesis & degradation
  - o protein structure (representation, folding etc.)
  - o protein function, enzymatic activities
  - o major signal transduction pathways

- -Membrane biophysics
- -Beyond the cell:
  - o Development, embryology.
  - o Multi-cellular organisms, systems biology (organs)
  - o 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

Introduction to statistical physics – IOGS students only (3 ECTS)

Lectures

- Preliminaries (outline, bibliography)
- Chapter I: Introduction
- Chapter II: Microcanonical ensemble
- Chapter III: Canonical ensemble
- Chapter IV: Grand canonical ensemble
- Chapter V: Quantum statistics

Tutorials

- Central limit theorem, two-level systems, and application to the rupture of a biological bond
- Single DNA molecule pulled by optical tweezers
- Paramagnetism and Ising model for ferromagnetism
- Ideal gas and Langmuir isotherms
- Fermi Gas

Modern optics -for students with biology backgrounds – (3 ECTS)

Optical microscopy : linear, nonlinear, super-resolution (3 ECTS)

This course provides a description of the basic principles in optical microscopy techniques. It is intended for non-specialists in optics.

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

- Raman Based microscopy
  - o Concept
  - o Coherent Antistockes Raman Scattering
  - o Surface enhanced Raman spectroscopy
  - o Stimulated Raman Scattering

- Photoacoustic microscopy
- Optical Coherence Tomography

And
- Opening to specialty courses
  - o Neurophotonics
  - o Super-resolution microscopy

Core courses – 12 ECTS

Advanced Quantum mechanics + Light matter interactions (6 ECTS)

APPROXIMATION METHODS IN QUANTUM MECHANICS
- Perturbation theory, variational method
- Application to the Stark effect and the Zeeman effect for a hydrogenoid ion.

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

FINE STRUCTURE AND HYPERFINE STRUCTURE OF ONE-ELECTRON ATOMS SYSTEMS of IDENTICAL PARTICLES
- Indiscernibility, 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

- of 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 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/rubidium), laser cooling ...

Laser physics & nonlinear optics (6 ECTS)

-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

-Non-linear optics

Practicum courses – All for 6 ECTS

High resolution atomic spectroscopy

- Single-mode tunable lasers (diode laser, dye laser)
- Absorption spectrum of atomic vapors (Cs, Rb) and molecular vapors (Iode)
- 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.

Laser and nonlinear optics

-Introduction session - Introduction to basics of optics
- o Gaussian beams
- o Optical resonators
- o Laser cavities and laser gain
- o Nonlinear optics
- o Parametric cavities and nonlinear gain

-Practicum #1 – Optical resonators and second harmonic generation
- o Basics of laser cavities: the Helium-Neon laser
- o Laser amplification
- o Passive cavities: the case of Fabry-Perot etalon
- o Second harmonic generation: an insight in nonlinear optics

-Practicum #2 – Diode-pumped Nd:YAG laser cavity
- o Diode pump characterization
- o Laser cavity stability, resonant laser mode and mode-matching
- o Laser slope: laser threshold and laser efficiency
- o Intra-cavity second harmonic generation

-Practicum #3 – Optical Parametric oscillator (OPO)
- o Parametric cavity stability, resonant parametric mode and mode-matching
- o Phase-matching characterization and polarization dependence
- o Nonlinear slope: parametric threshold and parametric efficiency
- o Application of the pulsed beams to time-resolved spectroscopy

-Final session – Modelling of some aspects (depending on measured data)
- o Geometry of resonant laser and/or parametric Gaussian beams
- o Angular spectral acceptance of second harmonic generation
- o Emission threshold and gain efficiency (laser and/or parametric cavity)
- o Rare-earth lifetime

Optical microscopy

Synthesis and characterization of materials for photonics

➢ Emitting compounds

o Synthesis of a RE doped glass and characterizations: XRD, density, transmission, refractive index and RE luminescence

o Heat treatment of the glass: evolution of the XRD pattern and emission properties

- Colored pigments

o Synthesis of $Cu(Mo,W)O_4$ compounds (at least 3 Mo/W ratios) and characterizations : Phase transition versus temperature (Kofler Bank), versus pressure (unixial press) and dependency versus Mo/W ratio, XRD (High and Low T° forms both stable at room T°)

Colorimetric parameters (RGB, XYZ, Lab spaces); sensitivity of the color versus pH). Discussion of the Kinetic of the phase transition.

Optics lab (for students with biology or chemistry backgrounds)

Basics of Geometric Optics and Modern Optics
-Image formation and diffraction gratings
-Gaussian beam propagation and diffraction
-Interferences and Michelson interferometer

Quantum practicum

SEMESTER 2

Core courses –6 ECTS

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 reorientatio

Molecular spectroscopy (PCCP)

Description

Understanding the fundamentals of light-matter interaction, molecular optical spectroscopy (electronic transitions and molecular vibrations).
-Analysis and interpretation 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 analysing 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.

Lectures:
- Light Matter Interaction.
- Molecular symmetry and vibrational analysis.
- TIR spectroscopy.
- Raman spectroscopy.
- Applications in molecular science.
- Optical constant in materials.

IR specular (ATR, IRRAS) and diffuse (DRIFT) reflection techniques IR analysis of anisotropic and chiral material
-Raman spectroscopy in materials.
-Raman imaging and micro spectroscopy.

Specialisation courses –12 ECTS

Ultrafast optics and laser processing (3 ECTS)

- 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; Polarisation 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

Molecular Photonics (3 ECTS)

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, material from Chapters 1, 2 and 3 of MMP. 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 (1) electronic energy transfer (Chapter 9) and the two basic mechanisms of energy transfer (electron exchange and dipole-dipole mechanisms); (2) the paradigms for determining photochemical mechanisms (Chapter 8); (3) theory of the fundamental photochemical primary processes (Chapter 7); (4) examples of each of the important photochemical primary processes and synthetic applications of photochemical reactions (Chapters 10-13).

Useful texts and references:

A. N. J. Turro, "Modern Molecular Photochemistry" (MMP), University Press, Menlo Park, CA,

1978.
B. A. Gilbert and J. Baggott, "Essentials of Molecular Photochemistry," CRC Press, London, UK, 1991.
C. J. Mattay and A. Griesbeck, eds., "Photochemical Key Steps in Organic Synthesis", VCH, New York, 1994.
D. J. D. Coyle, ed., "Photochemistry in Organic Synthesis", Royal society of Chemistry, London, 1986.
E. W. H. Horspool, ed., "Synthetic Organic Photochemistry", Plenum, New York, 1984.
F. Bryce-Smith, et. al, eds. Specialist Reports of the Chemical Society: D. Photochemistry (Annual reports on all of photochemistry since 1969).
G. I. Ninomiya and T. Naito, eds., "Photochemical Synthesis", Academic Press, Londaon, 1989.
H. J. C. Scaiano, ed., "CRC Handbook of Organic Photochemistry", vol. 1 and 2, CRC Press, Boca Raton, Florida, 1989.

Neurophotonics (3 ECTS)

This advanced course provides a description of state-of-the art optical microscopy techniques in the context of neurobiology.

- Basics about the brain
  - Macroscopic Architecture, brain areas
  - Molecular architecture
  - Neuronal communication
- Electrophysiology
- Neuro-samples: from artificially reconstituted systems, cell culture to brain slices and in vivo brain samples
- Optical properties of brain tissues
- Theory (see also Optical microscopy and Super-resolution microscopy courses) and application of advanced optical microscopy techniques to neurobiology:
  - Epifluorescence microscopy, FRET, FLIM
  - 2-photon, 3-photon excitation fluorescence microscopy
  - OCT, CARS, photo-acoustic imaging
- Deep brain imaging
- Calcium imaging
- Optical actuators and optical control, optogenetics, chemogenetics
- Revealing the connectome of a brain:
  - Clarity,
  - robotized slicing/imaging
- Lab courses

Materials for photonics (3 ECTS)

1- Materials for light transport: glasses and polymers, elaboration, playing with the index (composition, adaptation of index for the layers), transmission (synthesis, purity, adapted

composition, ions giving rise to specific absorptions), nonlinear properties (supercontinuum, wave
mixing). Applications to photonic crystals, fibers, lenses ....
2- Luminescent and colored materials: crystalline powders, crystals, glasses, elaboration. Origin of color in materials, physics of color, color space. Orientation of crystals, defects, shaping, relationship between site and absorption. Applications: medicine, lighting, energy conversion, visualization...
- Characteristic quantities and properties of plasmas.

Physics of fluids and transport (3 ECTS)

Lectures in French.

- 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 (3 ECTS)

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

Introduction to physics of soft matter and complex systems (3 ECTS)

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

Optoelectronics (3 ECTS)

Internship –12 ECTS

SEMESTER 3

Specialisation courses –12 ECTS

Quantum optics (3 ECTS)

- 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 (3 ECTS)

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.

Nanophysics (3 ECTS)

- 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 nano-electronics.
-Spintronics. Giant magnetoresistance. Magnetic moment manipulation via the electric current.

Lab courses:
Magnetism and light interaction in solid state/ Light and magnetism in quantum materials
Light and superconductivity
Dirac materials and topological insulators

Attosciences and related technologies (3 ECTS)

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

Advanced statistical physics (3 ECTS)

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

Optics of nanomaterials (3 ECTS)

- 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

Biophysics (3 ECTS)

- 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.

Nano-opto-electro mechanics (3 ECTS)

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.

Extreme Light interactions and attosciences (3 ECTS)

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

Laser-plasma interactions (3 ECTS)

Pre-requisite: Introduction to plasma physics (3 ECTS)
Collective behavior of a fluid or a gas of charged particles in the presence of external and self-consistent 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.

Lab courses –18 ECTS

Students can choose a total of 18 ECTS from the following list:

Laser-generated plasma (9 ECTS)

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 (6 ECTS)

This training takes place at the Bordeaux Imaging Center (https://www.bic.u-bordeaux.fr/). 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) (3 ECTS)

This training takes place at several partner universities from Fotonika (Euskampus photonis 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 (6 ECTS)

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 Course (3 or 6 ECTS)

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.

SEMESTER 4

Master thesis – 30 ECTS