Course title : **Fundamentals in Biology**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
5	**Mandatory**	**Biology**	1	60	**Lectures + tutorial works**	English	ENS Paris Saclay	Clémence Richetta

Prerequisites: This course is mandatory for students having a limited background in Biology, (e.g. electrical engineers, computer scientists, mathematicians, physicists)

Objectives: To provide a basic training to non-biologists and to offer them a quick initiation to the various fields of life sciences. This training will allow students to choose biology-oriented modules of the Erasmus Mundus Master at the interface of physical sciences and molecular/cell biology.

Related courses: For non-biologists, prerequisite of the "Fluorescence in Biology" courses and all courses with a strong content in Biology

Contents	Lecture
	n hours
Lectures	
Structures and interactions of biomolecules (Brahim Heddi and Marco Pasi)	16
Structural biology methods (Brahim Heddi and Marco Pasi)	5
Introduction to classical genetics/ mitosis and meiosis (Marie Regairaz)	3
DNA replication and DNA repair (Marie Regairaz)	2
DNA Transcription and translation (Marie Regairaz)	2
Molecular biology methods (Marie Regairaz)	5
Internal organization of eukaryotic cells and functions of organelles (Clémence Richetta)	6
Cell signaling (Moniteur)	2
Eukaryotic Cell death and differentiation (Moniteur)	2
Diversity of the living world (Clémence Richetta)	2
Cells in their social context: example of the immune system (Clémence Richetta)	3
Introduction to microbiology: host-interaction (viruses, bacteria) (Clémence Richetta)	3
Cellular biology methods (Clémence Richetta and moniteur)	5
Neurone: synaptic communication- electrophysiology (Brigitte Potier)	2
Main functions of the brain and neurotransmitters (Brigitte Potier)	2

Evaluation method*:* Written examination: 100%

List of teachers: Clémence Richetta, Marie Regairaz, Brahim Heddi, Marco Pasi, Brigitte Potier

Recommended or required readings:

Life: The Science of Biology, 7th Edition, **William K. *Purves*, David Sadava, Gordon H. Orians, H. Craig Heller,** W.H.Freeman & Co Ltd

Course title : Practical work

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3		All the fundamentals	first	30	Practical work	English	ENS PS / ISMO / IOGS	A. Fragola

Prerequisites : basics in ray optics, wave optics, optical alignment, signal and image acquisition and processing

Objectives :
The aim of this course is to enable students to acquire practical skills linked to all the core courses in the Master's program, and to reinforce their knowledge in these areas through experimental learning. This module is organized into 7 practical sessions, each lasting 4 hours, and a 2-hour feedback/evaluation session.

The 7 sessions are chosen from a list of practical exercises covering the core courses of the Master's program (Fundamentals of Biology, Fundamentals of Chemistry, Light-Matter Interaction, Biomolecular Photonics, Microscopy, Fundamentals of Electrical Engineering and Soft Matter), and will enable students to learn more about one of these topics according to their interest.

Practical sessions are carried out on advanced commercial systems or on research set-ups in the laboratories of ENS Paris Saclay, ISMO and IOGS.

Related courses : Fundamentals of Biology, Fundamentals of Chemistry, Light-Matter Interaction, Biomolecular Photonics, Microscopy, Fundamentals of Electrical Engineering and Soft Matter

Contents

Pratical sessions : 28h total	*hours*
1: Fundamentals of Biology qPCR (2h) flow cytometry (4h) molecular graphics in structural biology (4h)	10
2: Optical microscopy imagerie sans marquage : OCT, imagerie de phase microscopie confocale microscopie à super-résolution : SMLM, STED imagerie en profondeur : light sheet microscopy	8 or 12
3: Fundamentals of Electrical Engineering	4 ou 8
4: Fundamentals of Chemistry or Light-Matter Interaction chemisty pince optique	4

Evaluation method *:* oral presentation

Students are divided into pairs and are required to keep a workbook up to date throughout the sessions. Each pair will be assessed during an oral presentation followed by questions (from the jury as well as other students) on one of the subjects chosen at random. All students attend the various oral presentations, so as to benefit from the experience of the other students, especially for the practical sessions they have not attended.

List of teachers: Alexandra Fragola and colleagues

Course title : Biodevices : cell biochips, from the single cell analysis to organ on chip

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	TCommun	**Biology Engineering**		30h	Lecture TD Lab hours Paper reading	English	ENS paris saclay	Bruno Le Pioufle

Prerequisites : This course is open to multidisciplinar background students.

Objectives : The basics of electrical engineering for the biology will be provided to students during this course.
This course proposes to review the most recent research and technologies developed in academy and industries for the electrical handling, sensing and treatment of cells. The cases of single cell analyses on a chip, as well as cell tissue reconstitution on a chip (organ on chips) will be addressed. Practical course, where the student will experiment the handling and treatment of cells within microfluidic devices, and compare to the theory and finite element simulation are part of this teaching.

Contents: This course browses the main electrical engineering aspects for the living cell monitoring and treatment, and introduces the latest research and industrial developments in micro and nanotechnology devoted these biological applications. Firstly, the course will give the principles of the electrical impedance measurement of cells, in order to estimate the electrical properties of membrane and cytoplasm. Such measurement is crucial for instance for cancer detection. Single cells as well as cell tissues will be considered. Secondly the principle of dielectrophoresis, broadly used for the handling and sorting of cells within microfluidic devices will be introduced. The possibility of electrical cell treatment using the electrical field pulses will then be presented. Finally, the course will introduce the concept of organ on chips.

	Lecture	Lab Work
1. Electrical monitoring of cells - Single cell electrical characterization using bioimpedance Maxwell-Garnett mixing theory, multishell model, single shell model, thick membrane simplified model, complex permittivity of the cell and the mixture, double layer capacitance of the electrodes, estimation of the cell parameters - Cell tissue characterization using impedance Frike Model, Cole-cole model, phase constant element, estimation of the cell tissue parameters - Electromechanical characterization of cells : electrorotation of cells and vesicules, Clausius-Mossotti factor, fitting to a model, - parameter estimation, from bioimpedance or electrorotation measurements - Case of study cell impedance measurement on a chip (paper reading exercices)	*6h cours* *2hTD*	
2. Cell handling and sorting with the electrical field - Polarization of cells, principle of the dielectrophoresis - Cell trapping/sorting using the dieletrophoresis - Cases of study of single cell sorting on a chip (paper reading exercices)	*6h cours* *2hTD*	
3. cell treatment with the electric field - concepts of electroporation and nanoporation - towards the electrochemotherapy - Case of study of single cell electroporation on a chip (paper reading exercices)	*3h*	
4. Organ on chip	*2h cours* *2hTD*	
Practicals – Laboratory (possible choice possible for students)		8h

Dielectrophoresis on a chip (4h), Bioimpedance measurement of a Tissue (4h) MODULE TP →Electrorotation experiment (4h) MODULE TP→Dielectrophoresis force simutation with finite element analysis (4h),		

Evaluation method *: Writen exam (3h, coefficient 3)* + *presentation of a scientific paper (2h, coefficient 1),* + *Lab hour report (coefficient 1).*

Learning outcomes : cell handling and treatment on a chip, concept of organ on chip

List of teachers : Bruno Le Pioufle & Sakina Bensalem

Course title : **Fundamentals in Chemistry**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional All students	**Chemistry**	1	30	**Lecture**	English	ENS Paris Saclay	Nicolas BOGLIOTTI

Prerequisites: This course is mandatory for students having a limited background in Chemistry.

Objectives: This course is an overview of important and fundamental aspects of chemistry. Basic principles, necessary to understand chemistry and contiguous scientific fields, are given.

Contents	Lecture
	n hours
Part I: Molecular Chemistry **1. Chemistry of the Elements** Models for atoms and electrons description. Electronic configuration. Periodic table and element properties. **2. Organic molecules** Chemical bonds. Molecular structure and geometry. Aromaticity. Functional groups. Conformation and configuration. **3. Non-covalent interactions** Ion-ion, ion-dipole, dipole-dipole, hydrogen bond, halogen bond, aromatic interaction, cation-π, anion-π, van der Waals	~18
Part II: Physical Chemistry **1. Thermodynamics** Enthalpy, Gibbs energy and entropy. Chemical equilibrium. **2. General Chemistry in Solution** Acid, bases and pH. Complexation. Solubility and polarity effects. **3. Kinetics** Reaction rate. Reaction mechanism. Catalysis **4. Basics of Surface Chemistry**	~12

Evaluation method*:* Written examination.

Learning outcomes: Mastering basic notions in chemistry enabling students to follow the courses in contiguous fields.

Recommended or required readings:

"Chemistry^3 - Introducing Inorganic, Organic and Physical Chemistry" A. Burrows, J. Holman, A. Parsons, G. Piling, G. Price.
"Physical Chemistry", P. Atkins.
"Physical Chemistry - Understanding our Chemical World" P Monk.
"Introduction to Organic Chemistry » W. H. Brown, T. Poon

List of teachers: Nicolas Bogliotti, Cédric Mongin

Course title : **BioMolecular Photonics**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	**Optional**	**Biophotonics**	1	28	**Lectures**	English	ENS Paris Saclay	Eric Deprez

Prerequisite: Fundamental in biology

Objectives: This course will provide theoretical knowledge required to understand experimental methods underlying fluorescence-based assays for biology at the molecular level: (i) photoluminescence & photoreactivity (excited state, (non)radiative relaxation pathways, photoisomerization…), (ii) steady-state & time-resolved parameters/methods, (iii) main intrinsic/extrinsic fluorescent probes used in biology and (iv) biological applications (quantitative PCR, flow cytometry). The students must have understood the principle of these techniques and to be able to master them quickly in an experimental environment.

Related courses: Microscopy adv, Light-matter interaction, UE TP

Contents	
Lectures	***n hours***
- Introduction to fluorescence / photoreactivity (Eric Deprez	8
- Time-resolved fluorescence analysis (Eric Deprez)	2
- Fluorescent probes in biology (Bertrand Cinquin)	2
- Intrinsic fluorescence (*e.g.* protein fluorescence) & fluorescence quenching (Eric Deprez)	2
- Steady state & time-resolved fluorescence anisotropy (Eric Deprez)	3
- Fluorescence (cross)correlation spectroscopy (Bertrand Cinquin)	2
- Introduction to FRET (fluorescence resonance energy transfer) / FRET-FLIM (Eric Deprez)	2
- Single molecule FRET – Introduction to TIRF microscopy (Karen Perronet)	3
- Quantitative PCR (Olivier Delelis)	2
- Flow cytometry (Clémence Richetta)	2

Evaluation method*:* Written examination

List of teachers: Eric Deprez, Bertrand Cinquin, Karen Perronet, Olivier Delelis, Clémence Richetta

Recommended readings: Joseph R. Lakowicz, *Principles of fluorescence spectroscopy*. Third edition. Springer (2006).

Course title : **Light-Matter Interactions: from Molecules to Solids**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	**Optional**	Physics/chemistry	1	30	**Lectures Exercises Lab visits Seminars**	English	ENS Paris-Saclay	Emmanuelle Deleporte Keitaro Nakatani

Prerequisite: Quantum physics, hydrogen atom, introduction to condensed matter (band structure of solids), Schrödinger equation, molecular orbitals, chemical kinetics

Objectives: In the context of light-matter interaction, this course focuses on the effect of light on molecules and solids: what happens to them?: formation of excited states, what are the outcomes? non-radiative and radiative relaxation phenomena from the excited states. Concepts and models to describe such interactions and resulting phenomena (absorption, emission) will be introduced and developed in parallel for molecules and solids, highlighting the analogies, similarities and specificities between these two systems. An objective of the course is then to connect worlds at different scales and have a complete and general overview on the optical properties in matter. The experimental means to observe the optical properties will be described and the introduced concepts and models will be illustrated by current research subjects, beyond textbook cases.

Related courses: Laser and Nonlinear Optics, Nanophotonics, quantum sensing

Contents	
Lectures	***n hours***
Introduction: overview on the conceptual tools and phenomena (ED, KN)	
From Schrödinger equation to ...	1.5 h
Molecules: *Molecular orbitals - Energy levels - Jablonski-Perrin diagram*	4.5 h
Solids: *Band structure of semiconductors - Different dimensionalities: quantum well, quantum wire, quantum dot - Phonons in a solid*	
Ground to excited states: light absorption	
Molecules: *Selection rules - Transition moment - Molecular physicochemical properties at excited states*	6 h
Solids: *Absorption coefficient: interband optical transitions, selection rules, density of states - Properties at excited states: excitons*	
Excited to ground states: light emission and other mechanisms	
Molecules: *Non-radiative relaxation mechanisms: vibrational relaxation, internal conversion, inter-system crossing - Photoluminescence (fluorescence and phosphorescence): quantum yield, lifetime, emission and excitation spectra*	6 h
Solids: *Intraband non-radiative relaxation (electron phonon interaction) - Photoluminescence (electron-hole recombination): quantum yield, lifetime, emission and excitation spectra*	
Complex processes	3 h
Molecules: *Fluorescence quenching - Energy transfer (FRET: Förster resonance energy transfer)*	
Solids: *Energy transfers - Charge transfers*	
Exercise sessions (ED, KN)	
Seminars - Examples from research	
Molecules: Photochemical reactions and photo-active molecule	6 h
Solids: Optical properties of hybrid halide perovskites	3 h
Lab visit - Instrumentation	

Evaluation method: Written examination based on research articles
List of teachers: Emmanuelle Deleporte (ED) - Solids, Keitaro Nakatani (KN) - Molecules
Recommended readings:

- Physical Chemistry, P. Atkins et al., Oxford University Press
- Photochemistry of Organic Compounds: From Concepts to Practice", P. Klan and J. Wirz, Wiley-Blackwell
- Molecular Fluorescence, B. Valeur and M.N. Berberan-Santos, Wiley-VCH
- Optical Properties of Solids Mark Fox, Oxford Master Series in Physics, Mark Fox, Oxford Series in Physic

Course title : Advances optical Microscopies

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	Optics	first	28	Lectures	English	ENS PS	F. Treussart

Prerequisites : bases in fluorescence, ray optics, wave optics

Objectives :
The aim of this course is to present different optical microscopy methods useful for studying biological samples at the cell and tissue scales. We will start by introducing the basics of optical microscopy (characteristics of a microscope objective, illumination configurations, notions of depth of field, resolution limits…).
We will then turn our attention to fluorescence microscopy, and in particular to super-resolution techniques. Different techniques, such as STED, PALM or STORM will be presented. Compromises between spatial and time resolution will be discussed (structured illumination microscopy) as well as super-resolution in the optical-axis direction (PSF engineering).
We will then see how multi-photon microscopy and adaptive optics provide a way to image deeper in the biological tissues.
We will finally focus on fast imaging, to study live biological samples. Techniques as single-particle tracking and resonant two-photon imaging will be introduced.

Related courses : Molecular Photonics, light matter interaction, fundamentals in biology

Contents

Lectures	*hours*
1: Fundamentals of optical microscopy Structure of an optical microscope, Köhler configuration, phase contrast imaging, depth of field, spatial resolution.	6
2: Fluorescence microscopy and super-resolution techniques: imaging with nanometer-scale resolution Based on examples with biological applications.	8
3: Deeper in tissue Use of multi-photon microscopy and adaptive optics. Examples from neurosciences.	6
4: Faster: how to image in real-time living samples Tracking methods, resonant 2-photon imaging, functional imaging.	8

Evaluation method *:* Written exam

Learning outcomes
At the end of this course, students will be able to analyze and design advanced optical microscopy set-ups for biology. This will make it easier for them to use systems available on imaging platforms, and to consider internships and theses in research laboratories developing new microscopy methods for the study of biological samples.

Recommended or required readings
"Introduction to Optical Microscopy", Jérôme MERTZ, Cambridge University Press, 2nd edition (2019)

List of teachers: François TREUSSART, Alexandra FRAGOLA

Course title : **Soft Condensed Matter**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional All students	**Physics**	1	30	**Lecture**	English	ENS Paris Saclay	Giuseppe FOFFI

Prerequisites: This course requires a good knowledge of Statistical Mechanics.

Objectives: This course is a general introduction to the world of soft matter. In particular, we will use the tools of Statistical Mechanics to discuss the equilibrium, the dynamical and mechanical properties of soft matter systems and we will explore different applications ranging from Material Science to Biophysics.

Contents	Lecture
	n hours
Part I: Statistical Mechanics of Interacting Systems: Appl **1. Review of Stastical Mechanics** Postulates of Statistical Mechanics, Gibbs Ensembles, from micro to macro. Ideal systems. **2. Non-Ideal Systems and Virial expansion** Ideal systems and they role in soft matter. Complexity and phase transition. A first treatment introducing the virial expansion. **3. Density Distribution Theory** Introduction to the liquid state theory. Density distribution and radial distribution function (RDF). Connection of the RDF to thermodynamics properties. Stati structure factor. Brief introduction to computer simulations. **4. Scattering Theory** Formal connection of the static structure factor with the scattering properties. Form factor. Performing scattering function in real life: SALS, SAXS, SANS. A brief introduction to Dynamic Light scattering (DLS)	~18
Part II: Intermolecular interactions **1. Introduction** Enthalpy, Gibbs energy and entropy. Chemical equilibrium. **2. van Der Waals interactions** Origin, simple derivation, from microscopic to macroscopic interactions. **3. Electrostatic Interaction** Poisson-Boltzman equation, Debye-Huckel Theory, DLVO interactions and aggregation TDs: Applications Ideal statistical mechanics and absorption of Oxygen by Haemoglobin. Dense solution of proteins as non-ideal systems. Osmotic Pressure. Depletion interaction.	~12

Evaluation method*:* Written examination.

Learning outcomes: Introduction to the world of soft matter and to new tools in statistical mechanics.

Recommended or required readings:

Any introductory Statistical Mechanics book.
Good reference for Part I and II: David L. Goodstein - *States of matter*
Notes of course

List of teachers: Giuseppe Foffi

Course title: **Advanced Python for Big Data Exploration and Visualisation**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3		**Informatics Data analysis**		30	**Lecture Lab hours**	English	ENSPS	Marco PASI

Max size : 10 students

Prerequisites : Basic Python programming; basic statistics.

Objectives : Python is a simple, multi-purpose language that is a reference in data science (statistical analysis of data and machine learning). This course focuses on the Python tools and libraries needed for high-performance manipulation, visualization and exploratory statistical analysis of large experimental datasets, as well as constructing and training statistical models to make predictions based on the data. The course is fully hands-on, and uses effective teaching techniques (e.g. live coding, active learning) to tackle modern problems in data science and emerging practices to solve them.

Related courses :

Contents	Lecture *hours*	Lab Work *hours*
1. Programming Python basics (Homework: 6h) Data types, control structures, lists, hashes, files	0	0
2. Data Manipulation using `pandas` Reading, storing and sharing large datasets, indexing/slicing/iterating, vectorization, dataframe operations.	2	4
3. Data Visualisation using `matplotlib` and `seaborn` Visualising data for exploration and for publication, data science traceability and reproducibility.	2	4
4. Exploratory Data Analysis using `pandas` and `seaborn` Finding relationships between variables, formulating hypotheses and devising models.	2	2
5. Basic statistical modelling using `scikit-learn` Constructing and training simple models to make predictions based on the data.	3	3
6. Personal/group project Prepare a report about the exploratory analysis and statistical modelling of a real dataset (chosen by the students or proposed by the teacher)		8

Evaluation method : Data analysis project report

Learning outcomes : Independence in the choice of techniques and strategies for the exploratory analysis of large sets of experimental data using Python, from experiment to publication-ready figures.

Recommended or required readings : Python for Data Analysis: Data Wrangling with Pandas, NumPy, and IPython (O'Reilly, 2011) W. McKinney; Introduction to Machine Learning with Python (O'Reilly, 2016) A. Mueller and S. Guido.

List of teachers : Marco PASI

Course title : Biodevices : Ion Channel Recording and nanopore technology

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	TCommun	**Biology Engineering**		30	Lecture TD Lab hours Paper reading	English	ENS paris saclay	Bruno Le Pioufle

Prerequisites : This course is open to multidisciplinar background students.

Objectives : The basics of electrical engineering for the biology will be provided to students during this course.
This course proposes to review most recent research and industrial developments in micro and nanotechnology devoted to the electrical characterization of ion channels, for electrophysiology purposes, as well as the use of those ion channels as sensing devices for single molecules sensing (DNA, proteins..). Practical courses, where real experiments are conducted on biomicrosystems, are confronted to the theory and simulation are proposed in the framework of this course.

Contents :This course browses the main electrical engineering aspects for the living cell monitoring, from the basics of electrophysiology to the latest research and industrial developments in micro and nanotechnology devoted to biological applications. The impact of nano and microtechnologies on biology is quite huge, as demonstrated by the DNA chips that became nowadays a commonly used technology for many applications. The principle and fabrication of DNA chips will be presented. Then the course will focus on protein chips – soluble proteins or membrane proteins - and more particularly on devices used to characterize and monitor ion-channel proteins. Main architectures of microfluidic devices found in the literature devoted to this purpose will be described, based either on the reconstitution of planar lipid bilayers or on the droplet contacting principle.
Finally, the use of those ion-channels as natural nanopores can be used for electrically sense the properties of single molecules. The fabrication of devices for such a purpose will be described, and scientific papers on the subject will be analysed.

	Lecture	Lab Work
1. DNA chip concept of successive photoexposures to develop high throughput chips	*4h*	
2. The electrical field within the cell - Basics in electrophysiology, - Huxley model of action potential propagation, Simulation of the Action potential (practicals), Resolution of the propagation of electrical signal (co-axial cable vs Axon)	*6h*	
3. Electrical monitoring of ion-channels - Main systems for ion channel recording, patch clamp, planar patch clamp, - Artificial lipid bilayers systems : Structure and fabrication of membrane protein chip, Liposomes, Giant liposomes, electroformation, droplet contacting method - Architecture and clean room microfabrication of the microfluidic devices for ion-channel recording - Paper reading exercice	*6h cours* *2h TD*	
4. Nanopore sensing technology - Use of biological nanopores for the single molecule sensing - Use of solid state nanopores for large molecules sensing - Paper reading exercice	*6h cours* *2hTD*	
Practicals – Laboratory Simulation of the action potential (4h),		4h

Evaluation method *: Writen exam (2h, coefficient 3) + presentation of a scientific paper (2h, coefficient 1), + Lab hour report (coefficient 1).*

Learning outcomes : biochip fabrication, basis in electrophysiology, patch clamp, nanopore sensing

Recommended readings : Miller, C. *Ion Channels Reconstitution*; Plenum Press, 1986.

List of teachers : Bruno Le Pioufle & Laurent Bacri (or Juan Pelta)

Course title : Image analysis for biology

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	**Signal processing applied to biology**		30h course +4h practical	Lecture Exercises Lab hours	English	ENS paris saclay	Thomas Rodet

Prerequisites : This course is open to multidisciplinar background students.

Objectives : The objective of the course is to acquire the basic notions of signal and image processing in order to be able to solve imaging problems of biological structures. We will study the principles of obtaining super-resolved imaging approaches and partially overcoming light diffraction problems. But we will also study the problem of image processing in order to create automatic image processing. Finally, we will study sequences in order to solve cell tracking problems.

Contents: The course will present the necessary aspects of information theory to understand the different existing super-resolved microscopy systems. The main image processing methods allowing the detection and identification of biological objects will be presented and manipulated (for example automatic thresholding methods, mathematical morphology approaches, Hough transform parametric approaches, segmentation approaches' K-means'...). Finally we will tackle cell tracking. To do this, we will study global or local motion estimation approaches (block matching algorithms, optical flow, Kalman filter). And we will be introduced to the new artificial intelligence algorithm, based on deep neural networks (ResNet).

	Lecture	Lab Work
1. Super resolution for bio-microscopy	*6h*	
2. Cell detection : MorphoMat, image aspect, thresholding, segmentation (K-MEANS), De-noising	*10h*	
3. Cell tracking : Estimation movement, optical flow	*6h*	
4. Introduction to AI: ResNet	*8h*	
Practicals – Laboratory Introduction to image processing, application to a case study (cell detection and counting)		4h

Evaluation method : *Written exam (3h, coefficient 3) + Lab hour report (coefficient 1).*

List of teachers : Thomas Rodet & Sakina Bensalem

Course title: **Laser and Nonlinear Optics**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	Physics	1	30	Lectures Home works	English	ENS PS	Ngoc Diep LAI

Prerequisites: Optical physics and electromagnetism, Laser (Bachelor level)

Objectives: First to give basics of nonlinear optics and its applications to laser technology and applications. Second, to explore the relatively recent domain of nonlinear optics from to micro towards the nanoscale, including nonlinear effect in micro and nanostructures, nonlinear photonic crystals, as well as some far-field nonlinear microscopies and nanoscopies. Applications in physics and biology will be discussed.

Related courses: Light-Matter Interactions, Nanophotonics, Microscopies

Contents

Outline of the course	Lecture (h) 22 hours	Exercise (h) 8 hours
♦ Review of lasers	3	
▪ working principle		
▪ main properties, intensity		
▪ different kinds of laser		
▪ main applications		
♦ Introduction to nonlinear optics	4	
▪ general idea		
▪ reminder of linear optics		2
▪ a classical model for nonlinear effects	4	
♦ Nonlinear of bulk systems – coupled-wave theory		
▪ propagation equation		
▪ a fully treated useful example: non-resonant second-harmonic generation, phase matching and phase mismatching		2
♦ Second-order and third-order nonlinear optics	4	
▪ Second-harmonic and third harmonic generation		
▪ Parametric amplification, Pockel and Kerr effects, etc.		
♦ Nonlinear optics in micro- and nano-structures		
▪ Quasi-phase matching technique: structures 1D, 2D and 3D	4	2
▪ Nonlinear photonic crystals: perfect phase matching.		
▪ Fabrication and applications of nonlinear photonic crystals		
♦ Nonlinear microscopies and nanoscopies	3	2
▪ What does (or does not) matter from bulk to nanoscale		
▪ Multi-photon microscopies in nanophotonics and biosciences: SHG, TPFE, THG, T3FE, CARS, EO, STED, structured illumination, ...		

Evaluation method: *Writing or oral exam (duration: 3 hours)*

Learning outcomes: The course enables the student to perform independent research in this field. In particular, students can understand, design and realize a new light wave by a frequency conversion method. Students will be able to explain and apply their knowledge of nonlinear optics to different research domains, such as physics, chemistry and biology, in particular at nanoscale.

Recommended or required readings: books **"Lasers"** – A. E. Siegman; "**Nonlinear Optics"** – R. Boyd

List of teachers: Ngoc Diep LAI (associate professor, ENS Paris-Saclay)

Course title: Quantum Sensing

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	Optics	2	30	Lectures & Tutorials	English		F. MARQUIER

Prerequisites: Quantum mechanics and basics of light-matter interaction

Objectives:
Understand how quantum states can improve the sensing of properties of different systems, and what are the limitations of quantum measurements. The concepts will be illustrated by examples of applications in physics and biology mostly based on nitrogen-vacancy centers in diamond.

Related courses: Light Matter Interactions, microscopy courses

Contents

	Lecture
	n hours
Each time slot is separated into a concept introduction and tutorials, often illustrated by scientific papers. The aim of the course is to highlight classical limits that can be overcome by a quantum approach of the measurements. The first part of the course will be dedicated to the notion of quantum bit and how to use it to measure an external parameter such as temperature, electric or magnetic field… We will see how the decoherence mechanisms limit the quantum measurement. Among the quantum sensors, we will particularly focus on negatively charged nitrogen-vacancy (NV) centers in diamond, a solid-state quantum sensor relying on an electron spin resonance that can be detected optically.	
General Introduction Light-Matter Interaction reminders: Optical Bloch equations and Bloch sphere: how to manipulate a Qubit? Notion of decoherence and decoherence in a quantum sensing experiment Introduction to classical noises in measurements Noise in a quantum sensing experiment	
• NV centers in diamond basics and optically detected magnetic resonance (ODMR)	1h
• Applications of ODMR to magnetometry and thermometry: continuous wave regime and pulsed regime (Ramsey interferometry)	2h
• Some physical and biomedical applications of NV-diamond magnetometry and thermometry	3h
• Decoherence in NV-center in diamond and application to sensing of biophysical parameters	3h

Evaluation method*:* Oral or written exam depending on the number of students

Learning outcomes – On completion of the course students should be able to:
- Know how to use a quantum state to perform a measurement and get a better signal-to-noise ratio.
- Understand some of the basic scientific papers in this field

Recommended readings
- "Introductory Quantum Optics", C.C. Gerry and P.L. Knight, Cambridge Univ. Press (2005)
- Degen, C. L., Reinhard, F. & Cappellaro, P. Quantum sensing. *Rev. Mod. Phys.* **89**, 035002 (2017).
- Aslam, N. *et al.* Quantum sensors for biomedical applications. *Nat. Rev. Phys.* **5**, 157–169 (2023).

List of teachers: François MARQUIER and François TREUSSART

Course title: **Modeling structure and dynamics of biomolecules**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3		**Physics** **Biology**		30	**Lecture** **Lab hours**	English	ENSPS	Marco PASI

Max size : 10 students

Prerequisites : Fundamentals in Biology, or equivalent prior knowledge

Objectives : Biomolecules adopt a dynamic ensemble of conformations to perform a multitude of cellular functions. In only a few years, structural biology, the study of the 3D structure or shape of proteins and other biomolecules, has been transformed by breakthroughs from machine learning algorithms. Despite all this progress, there are still many active and open challenges for the field, at the interface of Physics, Biology and Mathematics. This course will present recent advances and future perspectives, focusing on the complementarity of physical and statistical approaches.

Related courses :

Contents	Lecture	Lab Work
	n hours	*l hours*
CM:		
1. Elements of quantum chemistry	3	
2. The space of biological sequences and structures (M Pasi) Multiple sequence alignments, conservation and (co-)evolution.	4	
3. Protein structure prediction: physics and statistics (M Pasi) The protein folding problem: approaches from physics (Anton) and statistics (AlphaFold).	4	
4. Theoretical bases of molecular mechanics (M Pasi + D Perahia) Biomolecular empirical force fields: principles, approximations, common functional forms, the solvent, performance considerations, applications.	4	
5. Sampling the potential energy surface (M Pasi + D Perahia) Algorithms and techniques (minimisation, Monte Carlo, molecular dynamics, Normal modes)	4	
TP:		
5. Quantum chemistry using Gaussian		3
6. Modelling structure (M Pasi) From sequence to structure using machine learning; evaluating quality and limitations of models; using molecular viewers to study biomolecular structure and interactions and gain physical insight into the biological phenomena		6
7. Modelling dynamics (M Pasi) From static structure to trajectory in physiological conditions; extracting useful information from the trajectory to evaluate simulation quality, compare with experiment and shed light on molecular mechanisms		6

Evaluation method : Oral exam including lab work report.

Learning outcomes : Understanding the interplay of physics- and statistics-based approaches to study biomolecular structure and dynamics; deciding whether molecular modelling can be useful in a research project; understanding the relationship between models, simulations and experiments; setting up a molecular dynamics simulation, analysis and visualization of simulation results.

Recommended or required readings : Molecular Modelling: Principles and Applications (Pearson Education, 2001), A. Leach; Understanding Molecular Simulation: From Algorithms to Applications (Academic Press, 1996) D. Frenkel & B. Smit; several recent scientific publications.

List of teachers : Marco PASI, David PERAHIA, …

Course title : **Microfluidics – Biosensors – Biodevices : Fundamentals and applications**

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	**Biology Engineering** N.Tesla		30h	Lecture Exercises (TD) Lab hours Oral presentation	English	ENS Paris-Saclay	Sakina Bensalem

Objectives : Microfluidics lectures aim to introduce students to fluid mechanics at the microscale, in the framework of lab-on-a-chips and their technology associated. Fluid mechanics at the microscale has the particularity to be multiphysics. Lectures contain both theoretical backgrounds and microfabrication analysis. Examples of technical solutions illustrate the course. Practical work will give the possibilty for students to design, fabricate and characterise a microfluidic chip.

Related courses: ICR – Fundamentals in Electrical engineering

	Lecture	Lab Work
1. Introduction - Scaling laws in Microsystems	2h	
2. Microfluidic technology - Clean room, Photolithography and Microelectronics technology glass, silicon, polymer (molding-casting)	*2h*	
3. Physics of microfluidic - Poiseuille flow - hydrodynamic separation: wall effect, shear stress effect - Diffusion and mixing - Capillarity: digital microfluidics – Droplet - Case of study exercises	*6h cours* *2h TD*	
4. Microfluidics for the cell sorting and characterization - Acoustophoresis of cells in microfluidic devices - Magnetophoresis in cell chips - Dielectrophoresis separation within microfluidic devices - Amperometric sensing / convection-diffusion-consumption - Case of study (research paper reading exercises)	*8h cours* *2h TD*	
Practical training (8h) - Fabrication and testing of a micromixer in PDMS - Droplet generator and phase diagram characterization MODULE TP: Microfluidic sorting using hydrodynamic forces		8h

Evaluation method*:* 50%: Written exam (3h), 25%: oral presentation(30min), 25%: lab work report.
Learning outcomes: This lecture gives a wide knowledge of microfluidic principle in both physics and microtechnologies associated. Students are able to design a system involving microfluidic constraints (Identify, model and solve microfluidic problems taking into account size réduction impact). Lab works make connection with conducting experiments in the field of microfluidic in both flow or pressure control.

Recommended or required readings:

Fundamentals and applications of Microfluidics, Nguyen and Wereley, Artech House
Introduction à la Microfluidique, P. Tabeling, Belin
Theoretical Microfluidics, H. Bruus, Oxford University Press

List of teachers:
Sakina Bensalem

Course title: Nanophotonics

ECTS	Type	Discipline	Semester	Number of hours	Mode of delivery	Language	Place	Person in charge
3	Optional	Physics	2	30	Lectures	English	ENS PS	Ngoc Diep LAI Bruno Palpant Jean-Sebastien Lauret

Prerequisites: Optical physics and electromagnetism (L3 level), basic mathematical physics notions in classical and quantum mechanics (L3 level), and Light-matter interactions course (M1 level)
Objectives: This course aims at giving knowledge from a basic background of photonic crystals and plasmonics and applications in different domains, including physics/bio/chemistry, and in particular at single molecule scale.
Related courses: Laser and Nonlinear Optics, Light-matter interaction, Advanced Microscopies, Quantum sensing
Contents

Outline of the course	Lecture 30 hours
♦ PART ONE: Photonic crystals/nonlinear photonic crystals and applications ▪ 1D, 2D, and 3D photonic crystals: theory, simulation ▪ Photonic crystal and photonic quasi-crystals ▪ Photonic crystal with defect and applications ▪ Nonlinear photonic crystals ▪ Fabrication technologies and applications	10
♦ PART TWO: Plasmonic effect ▪ *Electromagnetism and optics in bulk noble metals*: Electromagnetism survival kit; Bulk noble metals: Electronic properties, optical response ▪ *Localised plasmon in metal nanoparticles*: Mechanical analogy: driven damped linear oscillator; Dielectric confinement; local field enhancement; applications for Surface-enhanced Raman scattering or fluorescence; bio-labelling; Effects of nanoparticle environment, size, shape and composition; Coupling between nanoparticles. ▪ *Transient optical response and nanoscale light-heat conversion*: Metal nanoparticles under laser pulses: Light-heat nanometric conversion; Thermo-optical properties ▪ *Selected applications*: Light-heat conversion: Nanoscale hyperthermia against cancer, drug or DNA delivery, laser damage and laser shaping, photothermal imaging, optical limitation	10
♦ PART THREE: Single molecules ▪ Energy levels in molecular systems; Light-matter interaction (from two level system to molecules) ▪ Single molecule spectroscopy: confocal spectroscopy, photon statistics… ▪ Single Molecules for BioImaging	10

Evaluation method: *Writing exam, based on scientific papers (duration: 3 hours)*.

Learning outcomes: The course enables the student to understand deeper the modern physics, the interaction of light and material at micro and nanoscale. Students will have a first imagination of inhabited physics, such as slow light or fast light, laser without threshold, etc. Students will be able to explain and apply their knowledge to different research domains, such as physics, chemistry and biology, in particular at nanoscale, what we cannot explain by the classical physics.

Recommended or required readings: book « Photonic Crystals Moulding the Flow of Light (Second Edition) » ; "Quantum Optics", M. Fox; "Quantum Mechanics", I et II C. Cohen-Tannoudji, B. Diu & F. Laloë

List of teachers: Ngoc Diep LAI (associate professor, ENS Paris-Saclay); Bruno PALPANT (professor, École Centrale Paris); Jean-Sebastien Lauret (professor, ENS Paris-Saclay).