Master of Chemistry

Track Chemistry & Life Sciences

2023-2024

PRESENTATION

The “Master de Chimie de Paris Centre” is a co-accredited training between PSL and Sorbonne University (SU). Rich and modular, it presents chemistry in a general and thorough way, both transversal and open to all of its interfaces, notably with physics and biology.

The track **Chemistry and Life Sciences** (C&LS or CSDV in French) is one of the tracks of this master. It is possible to join this track either at the M1 or M2 level.
The program Chemistry & Life Sciences aims at training highly motivated students interested in interrogating quantitatively and comprehensively biological systems at the molecular, cellular and network levels using various experimental and theoretical approaches. It allows students to develop their creativity through various research projects and internships, and to learn the latest discoveries and innovations at the chemical frontiers of living matter through privileged interactions with PSL faculty members.

See the dedicated websites: ENS Chemistry, PSL Université, Sorbonne Université

CURRICULUM of the C&LS track

MASTER'S YEAR 1

Semester 1 (30 ECTS)

- *Chemistry and Life Sciences Seminar Series (3 ECTS)*
- *n courses to be chosen (27 ECTS): see the courses offer in the following sections*

Semester 2 (30 ECTS)

- *20-weeks lab internship*

MASTER's YEAR 2

Semester 1 (30 ECTS)

- *Research design and project conception (6 ECTS)*
- *Chemistry and Life Sciences Seminar Series (3 ECTS)*
- *Current Challenges at the Chemistry & Life Sciences Interface (3 ECTS). If not followed in M1.*
- *n courses to be chosen (18-21 ECTS): see the courses offer in the following sections as well as all courses from the others tracks of “Master de Chimie de Paris Centre”*

Semester 2 (30 ECTS)

- *Master thesis (20 weeks)*

Important information:

For your first semester, you will have to define a program of studies. This program will be finalized during the first week, in agreement with the coordinators, but you can already build your program and send it to mathieu.morel@ens.psl.eu and mathilde.lepoitevin@ens.psl.eu for validation or advices.

Modus operandi: how to build your program of study?

You have to choose **30 ECTS** for your study contract (validating ECTS). It is also possible to follow courses as **extra ECTS**, the grades will appear in the final transcript but won't count in the average for graduation.

- **Important points for M2 students (but to be read also by M1s, see next point):** the lectures « Research design and project conception », « Current challenges at the C&LS interface » and « Master C&LS seminar series » are mandatory in the track « Chemistry and Life Science ». In addition, for the M2, **you need to choose at least 18 ECTS** among the courses highlighted in blue in the "CSDV courses" section. Note that the lectures « Master C&LS seminar series » and « Current challenges at the C&LS interface » are in this list.
- **For M1 students:** think of your program as a two-year program. As in M2 next year, you will have to take 18 ECTS in the "blue list", make sure you leave "blue" credits for next year.
- Pay particular attention to course schedules. Most Teaching Units are scheduled on a fixed half-day and on a weekly basis. However, some courses may have different schedules, particularly the biology courses at ENS are often condensed over 1 or 2 weeks.
- The study program can be exceptionally completed by 1 ECTS to meet the 30 ECTS required by providing reports of seminars followed during the semester.

Modus operandi: how to register for lectures?

- For most of the courses, **you will be automatically registered after validation of your study program.**

- However, some courses start the first week of September or require an early registration due to limits in attendees. If you plan to attend such courses, inform us as soon as possible (non-exhaustive list below):

- Bioinorganic Chemistry, ENS
- Statistical Mechanics and Simulations for Chemical and Biochemical Systems, ENS
- Nuclear Magnetic Resonance, ENS
- Scientific Communication, ENS
- Fundamentals in Biomaterials Science, Mines Paris
- Physico Chimie Analytique pour la bioanalyse et l'environnement, Chimie ParisTech

- **There is a specific registration process for courses at ENS-Biologie**

For the courses at ENS-biology (IBENS), you have to **register by yourself** on the website of the master IMALIS as an external student and for "**all the courses must be chosen at once"**.

https://www.enseignement.biologie.ens.fr/spip.php?article207

Before registration, contact the course coordinator for approval of course attendance (with mathieu.morel@ens.psl.eu in copy).
Some courses start early September and require an early registration. If you want to follow such courses, inform us as soon as possible (preferably before summer holidays)

Syllabi 2023-2024

CSDV **Courses**

Research design and project conception

Mandatory M2 only. This course doesn't count for the 18 CSDV ECTS.

Instructor in charge: Mathieu Morel (mathieu.morel@ens.psl.eu)

Year: M2 only
ECTS: 6
Format: Lectures & tutoring
Language: English

When: Friday afternoon
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This compulsory module aims at confronting students to the conception of a convincing research project, showing (i) how to define a scientific question or problem in the field of chemistry at the interface with life sciences, (ii) how to write a state of the art of the field, and (iii) how to propose a methodology to address and solve this question/problem.

Students will work in groups of 4-5 under the supervision of a tutor. Sessions will alternate general advices on grant application and scientific writing, with oral presentations of the advancement of group projects. At the end of the module, they will provide: (i) a written proposal, including a presentation of the question and the objectives, a state-of-the art and a proposed methodology, (ii) a video/media to popularize the project.

Program 2022-23:
Friday **16/09** 14h00-16h00: Introduction – What about Scientific Writing?
Friday **30/09** 14h00-17h00: Oral Presentations – Scientific Question(s) and Envisioned Solution(s) – *Tutor attribution*
Friday **07/10** 14h00-16h00: How to structure a Grant Proposal?
Friday **28/10** 14h00-17h00: Oral Presentations – State-of-the art & Project Positioning
Friday **25/11** 14h00-17h00: Oral Presentations – Project Implementation
Friday **09/12** 20h00: Due date for the written proposal
Friday **16/12** 14h00-16h00: Media Contest

5CI351 - Current Challenges at the Chemistry & Life Sciences Interface

Mandatory course in either M1 or M2

Instructor in charge: Domingo Gomez-Pardo (domingo.gomez-pardo@espci.fr)

Year: M1 or M2
ECTS: 3
Format: Lectures
Language: English

When: Thursday from 13:30 to 15:30
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This compulsory module consists in a series of conferences presenting current challenges at the Chemistry/Biology interfaces.

Validation: Writing of an original up-to-date bibliographic review (of between 3500 - 4500 words) on one of the presented topics.

- **Biological Imaging** (Ludovic Jullien, ENS)

- **Multi-scale modeling of biological systems** (Damien Laage, ENS)

- **Metals in medecine** (Gilles Gasser, Chimie Paris)

- **Bioorthogonal chemistry** (Boris Vauzeilles, Université Saclay)

- **Directed evolution - When chemists found inspiration in Nature's own method for optimising chemistry** (Arnaud Gautier, Sorbonne Université)

- **Synthetic & Systems Biology** (Yannick Rondelez, ESPCI)

- Inorganic cellular and biological chemistry (Clotilde Policar, ENS)

- **Studying the emergence and dynamic of Darwinian systems using droplet-based microfluidics** (Andrew Griffiths, ESPCI)

- **Machine learning for chemical and biological research** (Chloé-Agathe Azencott & Thomas Walter, Mines Paris)

- **Chemical Biology of epigenetics** (Paola Arimondo, Pasteur Institute)

- **Intrinsically disordered proteins: what can we learn from NMR?** (Fabien Ferrage, ENS)

5CI352 - Master Chemistry & Life Sciences Seminar Series

Mandatory course in M1 ***and*** *M2*

Instructors in charge: Gilles Gasser (gilles.gasser@chimieparistech.psl.eu)

Year: M1 & M2
ECTS: 3
Format: Seminars
Language: English

When: Thursday from 16:00 to 17:30
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This compulsory module consists in a series of seminars presenting the research at the Chemistry and Biology interface performed in the labs of PSL Research University.

Validation: Writing of a report presenting the seminars (one page per seminar).

Example of program (2021-2022):

30/09: Paola Arimondo (Institut Pasteur)
7/10: Kevin Cariou (Chimie ParisTech-PSL)
14/10: Fabien Ferrage (ENS-PSL)
28/10: Mélanie Ethève-Quelquejeu (Université de Paris)
11/11: Carlo Adamo (Chimie ParisTech-PSL)
18/11: Hélène Bertrand (ENS-PSL)
25/11: Kawthar Bouchemal (Paris-Saclay)
2/12: Davide Audisio (CEA)
9/12: Julien Nicolas (Paris-Saclay)
16/12: Virginie Mansuy (Sorbonne University)

5CI356- Les médicaments issus des biotechnologies

Instructor in charge: Pascal Bigey (pascal.bigey@parisdescartes.fr)

Year: M1 or M2
ECTS: 6
Format: Lectures
Language: **French only**

When: Thursday morning (*see the table below for 2022-2023)*
Where: Chimie ParisTech, 11 Rue Pierre et Marie Curie, 75005 Paris

Le but de cette UE, à l'interface de la chimie et de la biologie, est de présenter à un chimiste de formation tous les concepts qui lui permettront d'être un interlocuteur privilégié lors d'un projet en biotechnologies. Actuellement, environ la moitié des médicaments mis sur le marché correspondent à des molécules chimiques classiques obtenues par synthèse ou hémisynthèse organique, l'autre moitié étant des molécules issues des biotechnologies. Ces dernières sont également très utilisées en tant qu'outils diagnostic performants ou vaccins. Ces molécules peuvent être produites par synthèse (acides nucléiques courts) ou par cultures cellulaires (acides nucléiques longs, protéines). Quel que soit le mode de production, la chimie intervient sur ces molécules soit au niveau de la formulation d'administration, soit au niveau moléculaire pour obtenir des produits plus stables (acides nucléiques ou protéines modifiés, couplés). Il peut sembler important pour un chimiste d'avoir des notions de bases sur ces nouveaux médicaments très importants pour l'industrie pharmaceutique.
Au terme de cet enseignement un étudiant doit être à même de lire de manière critique des travaux de recherche publiés dans des revues spécialisées de chimie d'interface chimie-biologie.

Cours	**Date (22/23)**	**Horaire**	**Salle**
CM1/2	22/09	9:00 – 12:15	Chaudron
CM3/4	29/09	9:00 – 12:15	Chaudron
CM5/6	6/10	9:00 – 12:15	Chaudron
CM7/8	13/10	9:00 – 12:15	Chaudron
CM9/10	20/10	9:00 – 12:15	Chaudron
CM11/12	10/11	9:00 – 12:15	Chaudron
CM13/14	17/11	9:00 – 12:15	Chaudron
CM15/16	01/12	9:00 – 12:15	Chaudron
CM17/18	08/12	9:00 – 12:15	Chaudron
CM19/20	15/12	9:00 – 12:15	Chaudron
CM21/22	05/01	9:00 – 12:15	Chaudron
CM23/24	12/01	9:00 – 12:15	Chaudron
Exam	19/01/23	9:00 – 12:15	Chaudron

5CI357 - Médicaments: des robots et des hommes

Instructor in charge: Olivier Ploux (olivier.ploux@chimieparistech.psl.eu),

Year: M2
ECTS: 6
Format: Lecture
Language: **French only**

When: Tuesday afternoon (*see the table below for 2022-2023)*
Where: Chimie ParisTech, 11 Rue Pierre et Marie Curie, 75005 Paris

NB: En raison de la très forte demande, l'inscription à cette UE peut être limitée.

Cette UE propose de former les étudiants au domaine de la chimie médicinale moderne, en se plaçant résolument à l'interface Chimie-Biologie. Les grandes lignes de la conception d'un médicament seront abordées au cours de cours / conférences donnés par des acteurs du monde académique ou industriel. Les grandes classes de médicament, leur cible et leur mode d'action seront décrits. Les nouvelles méthodes de conception in silico seront abordées. Les grands principes de la chimie médicinale moderne seront présentés et illustrés.

Cours	Date (Tuesday)	Horaire	Salle
CM1/2	13/09	13:30-16:45	Amphi Chaudron
CM3/4	20/09	13:30-16:45	Amphi Chaudron
CM5/6	27/09	13:30-16:45	Amphi Chaudron
CM7/8	04/10	13:30-16:45	Amphi Chaudron
CM9/10	11/10	13:30-16:45	Amphi Chaudron
CM11/12	18/10	13:30-16:45	Amphi Chaudron
CM13/14	25/10	13:30-16:45	Amphi Chaudron
CM15/16	08/11	13:30-16:45	Amphi Chaudron
CM17/18	15/11	13:30-16:45	Amphi Chaudron
CM19/20	29/11	13:30-16:45	Amphi Chaudron
CM21/22	06/12	13:30-16:45	Amphi Chaudron
CM23/24	13/12	13:30-16:45	Amphi Chaudron
CM25/26	03/01/2023	13:30-16:45	Amphi Chaudron
CM27/28	10/01/2023	13:30-16:45	Amphi Chaudron
CM29/30	17/01/2023	13:30-16:45	Amphi Chaudron
Exam	24/01/2023	13:30-18 :00	Amphi Chaudron

5CI358 - Valorisation des bioressources

Instructor in charge: F. de Montigny (Frederic.de-Montigny@chimie-paristech.fr)

Year: M1 or M2
ECTS: 6
Format: Lecture
Language: **French only**

When: Tuesday morning
Where: Chimie ParisTech, 11 Rue Pierre et Marie Curie, 75005 Paris

Le module Valorisation des bioressources a pour objectif de :
- présenter des problématiques liées à la chimie végétal et raisonner sur des concepts allant de la biomasse aux biomatériaux en passant par les molécules plateformes...
- présenter des notions de chimie du végétal permettant de remplacer le carbone fossile par du carbone végétal, soit par une stratégie de substitution soit par l'élaboration de nouveaux matériaux biosourcés.
- d'aborder les notions : biomasse, biocarburants, prétraitements de la lignocellulose, molécules plateformes biosourcées, autres molécules d'intérêts biosourcées, biomatériaux.

Équipe enseignante : Régis Gauvin, Christophe Thomas, Carine Robert, Michel Minier, Frédéric de Montigny

Cours:
- Biomasse
- Prétraitements chimiques/physiques
- Prétraitements biologiques
- Molécules plateformes issues de la cellulose et de la lignine
- Catalyse associée à la valorisation
- Polymères biodégradables/ biosourcés
- Intervention d'un industriel

5CI359 - Statistical Mechanics and Simulations for Chemical and Biochemical Systems

Instructor in charge: Damien Laage (damien.laage@ens.fr)
Co-instructor: Guillaume Stirnemann

Year: M1 or M2
ECTS: 6
Format: lectures and numerical project
Language: English

When: Wednesday afternoon
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This course is aimed at both experimentalists and theoreticians. Its main focus is the molecular description of the dynamics of complex chemical and biochemical systems. It will cover both fundamental theoretical concepts in statistical mechanics and numerical simulation methods.
Their applications to a broad range of questions and systems will be discussed, ranging from chemical kinetics and diffusion to vibrational spectroscopy, biomolecular conformational dynamics and protein folding.
The course includes a simulation project which will provide students with an opportunity to apply the concepts and the tools presented in class by performing molecular dynamics simulations and analyzing the trajectories. This project is tutored and the results presented in a short-written report.

Lectures Program

1. From classical mechanics to statistical mechanics: Lagrangian, Hamiltonian, Liouville equation, ensembles
2. Time-dependent statistical mechanics: time correlation functions, diffusion, chemical kinetics, vibrational spectroscopy, energy transfer
3. Stochastic processes: Langevin equation, Brownian motion, friction, Fokker-Planck equation, mean first-passage time
4. Dynamics of quantum systems: quantum time-dependent statistical mechanics, path integral
5. Numerical simulations: molecular dynamics, accelerated sampling, hybrid quantum/classical descriptions, free energy calculations, descriptions of nuclear quantum effects

Prerequisite

This course requires a background in physical chemistry (L2/L3), statistical thermodynamics (L3) and chemical kinetics (L3).

5CI360 - Systems Chemistry of Living & Synthetic Matter

Instructors in charge: Ludovic Jullien (ludovic.jullien@ens.psl.eu), Mathieu Morel (mathieu.morel@ens.psl.eu)

Year: M1 or M2
ECTS: 6
Format: lectures, tutorials + group work
Language: English

When: Tuesday morning

Where: Sorbonne Université, 4 place Jussieu, 75005 Paris

This course has been conceived for students in chemistry with taste and curiosity for the chemistry/biology interface and who wish to enlarge their perspectives in biomimetic chemistry or synthetic biology.

This course aims at providing a rigorous physico-chemical description of biological phenomena which are rather singular to the eyes of the chemist, as exemplified by:

- Out-of-equilibrium and sustained enzymatic networks,
- Highly specific interactions and kinetic proof-reading,
- Dynamic self-assembly and compartmentalization,
- Fluctuations-regulated systems,
- Emergence of spatial organization and dynamics…

It will also equip with a solid cultural and conceptual background the chemists, who wish to reproduce some complex behaviors encountered in biology.
The module will alternate lectures and hands-on tutorials on image analysis and computational data analysis/modeling. With the help of tutors, students will propose both an “experimental” project based on available data (oral defense, 30%) and a “conceptual” project on their specific interest (written report, 40%).

Teaching objectives
- To reconstruct the behavior of living matter within an established physico-chemical framework;
- To locate the concepts and tools (experimental and computational) in the whole of physical chemistry for the analysis of complex biological systems;
- To formulate in precise scientific terms a scientific questioning and to evaluate its relevance according to the state of the art of knowledge and analysis tools.

Prerequisite
Essential: Notions of reactivity, thermodynamics, statistical mechanics, chemical kinetics.
Recommended: Basic notions of molecular and cellular biology

5CI361 - Chemical Biology for probing life and discovering drugs

Instructors in charge: Paola B. Arimondo (paola.arimondo@pasteur.fr), Arnaud Gautier (arnaud.gautier@sorbonne-universite.fr)

Year: M1 or M2
ECTS: 6
Format: lectures, articles analysis, oral presentation

When: Wednesday afternoon
Where: Sorbonne Université and Department of Chemistry of ENS

Chemical biology gathers a community of scientists interested in science encompassing both chemistry and biology. The reasons why chemists and biologists find a common interest in chemical biology are complementary: on one hand, for chemists, the complexity of biological systems appears like the ultimate playground in terms of chemical reactivity and analytical challenges; on the other hand, for biologists, chemistry appears like the most appropriate level of description to understand biological processes and develop new therapies.

Through examples, this course will present how chemical biology (i) provides a new framework for the design of chemical entities for discovering new drugs and inventing new therapies, and (ii) allows the design of innovative approaches to understand and manipulate biological systems in new ways.

Chemical Probes and Drug Discovery

- Introduction to drug discovery
- Nucleic Acids: biosynthesis and chemistry
- Carbohydrates: role, function, synthesis and potential in biomedical sciences
- Epigenetics: Introduction and Applications

Chemical biology approaches to understand and manipulate biological systems

- Bioorthogonal chemistry for labeling biomolecules in live cells
- Synthetic and genetically encoded fluorescent probes for illuminating cellular components
- Expansion of the genetic code to create proteins with new functions
- Molecular Glues for controlling cellular functions
- Chemical-genetic tools to study post-translational modifications
- Optochemical tools to control biological activities with light

Teachers

Paola B. Arimondo (CNRS - Institut Pasteur) ; Marcel Hollenstein (Institut Pasteur) ; Laurence Mulard (Institut Pasteur) ; Yves Janin (MNHN-CNRS) ; Anton Granzhan (CNRS Institut Curie) ; Arnaud Gautier (Sorbonne Université)

Teaching objectives

Learn how to understand biological systems using the knowledge of chemistry.
Be familiar with new ways to manipulate biological systems with the tools of chemistry.
Learn skills in research article analysis and oral presentation.

Prerequisite

This course requires basic knowledge about Proteins, Nucleic Acids and Carbohydrates (Structure, Molecular Recognition, Biocatalysis...), Organic Chemistry, Molecular and Cell Biology (Central Dogma of Molecular Biology, Cell Organization)

Dynamics of molecular processes in biological systems

Instructor in charge: Guillaume Stirnemann (stirnemann@ibpc.fr)
Year: M1 or M2
ECTS: 6
Format: Lecture, mini-project
Language: English

When: Thursday morning
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

** *This class is part of the ICI-PSL Master Track* **

Goals

- Appreciate the importance of dynamical aspects and processes (e.g. conformational dynamics, transport) in explaining the function of biological macromolecules;
- Gain a comprehensive overview of the relevant timescales, and of the available experimental and simulation techniques to probe such processes;
- Understand how the synergy between experiments, simulations and theory can lead to a comprehensive molecular picture of the involved mechanisms;
- Apply these concepts to practical cases, including examples from the literature and projects that will be led by the students.

Pre-requisites

Essential: Notions of thermodynamics, newtonian mechanics, statistical mechanics, chemical kinetics.
Recommended: Vector model of NMR, Classical mechanics (Hamiltonian, Lagrangian), Basic notions of molecular biology (biomolecules, structure)

Detailed program

1. Key concepts, experimental and simulation techniques (CM 28h, TD 6h)

Concepts and theories: Master equations for the study of dynamical processes (Guillaume Stirnemann, IBPC), Kinetic models for enzymatic catalysis (Damien Laage, ENS), Conformational motions, allostery, importance of transport and transfers in the cell (Antoine Taly, IBPC), Chemistry of systems: kinetics and stoichiometry (Philippe Nghe, ESPCI), Phase separation in biomolecular systems (Fabien Ferrage, ENS)

Experimental tools: Biomolecular dynamics from microseconds to seconds from chemical exchange NMR (Fabien Ferrage, ENS), Overview of other techniques // cryoEM, FRET, etc. (Fabien Ferrage, ENS), Microfluidics for controlled environments, analytics tools for dynamical networks (Philippe Nghe, ESPCI)

Simulation tools: Enhanced sampling techniques (Elise Duboue-Dijon, IBPC), Tools for reactivity, EVB, QM/MM (Damien Laage, ENS), Indirect dynamic techniques, NMA, PCA (Antoine Taly, IBPC)

2. Practical cases from the literature, key questions and challenges (5h)

5x1h devoted to 1 topic, may include: Dynamical effects in enzymatic catalysis; Allostery: positive, negative allostery, long-range effects of mutations (lac

operon?); Transport across the membranes: water, ions, NMs, nuclear pores; Networks of genetic regulations.

3. Hands-on sessions: basic simulations, projects (7h)

Basic simulations and illustration of the class' concepts: potential of mean force, kinetics of barrier crossing, NMA, clustering, Markov models, interpretation of NMR data…

Mini-projects based on literature and/or PI's work, each project includes some numerical analysis or very basic simulations. Max 6 groups/projects (1 per PI), 1-hr tutoring along the way. Short report and 2-hr poster session

Evaluation:

Final exam (50%), Mini-project (30%), Continuous evaluation (20%)

Fundamentals in biomaterials science

Instructor in charge: Laurent Corté (laurent.corte@minesparis.psl.eu)
Year: M2 only
ECTS: 3
Format: 8 x 3-4h classes + EXAM
Language: English

When: *Mainly Monday and Wednesday mornings* (subjected to changes)
Where: Arts et Métiers ParisTech, 151 Boulevard de l'Hopital, 75013 Paris

******** *This class is part of the BME Paris master and* ***availability is limited. Early registration is preferable.*** *Contact mathieu.morel@ens.psl.eu or mathilde.lepoitevin@ens.psl.eu if you want to follow this course*********

This series of lectures is an in-depth introduction to the design of materials for medical applications (biomaterials) and in particular for implanted applications (prosthesis, sensors, electrodes, drug delivery...). It provides fundamental knowledge about the phenomena occurring when materials are used in a living host and how these phenomena can be characterized and controlled. Notions specific to biomaterials are defined and illustrated with examples: biocompatibility, bioactivity, foreign body reaction and fibrosis, blood-materials interactions, systemic interactions... The main classes of materials used in biomedical applications (metals, ceramics, polymers, hydrogels) are presented with emphasis on the properties of interest for medical use and on the current research efforts to design devices with enhanced properties.

Prerequisite
Basic knowledge in cell biology.
Basic knowledge in physics and chemistry of matter.

2023-2024 Provisional Program

- **Mon. 18/09 (9h-12h30)** - Introduction to biomaterials science and technology (L.Corté, Mines Paris - PSL) + Introduction to immunology (S.Bessoles, U.Paris Cité)
- **Wed. 20/09 (9h-12h30)** - General concepts in biomaterials science (L.Corté, Mines Paris - PSL)
- **Mon. 25/09 (9h-12h30)** - Biomaterial-Host interactions I (L.Corté, Mines Paris - PSL)
- **Mon. 02/10 (9h-12h30)** - Biomaterial-Host interactions II (L.Corté, Mines Paris - PSL)
- **Wed. 04/10 (9h-12h30)** - Polymer biomaterials (L.Corté, Mines Paris - PSL)
- **Mon. 09/10 (9h-12h30)** - Hydrogels as biomaterials (C.Tribet, ENS - PSL)
- **Wed. 11/10 (9h-12h30)** - Ceramic biomaterials (M-H.Berger, Mines Paris - PSL)
- **Mon. 16/10 (9h-12h30)** - Metallic biomaterials (F.Prima & S.Fan, Chimie ParisTech - PSL)
- **Mon. 23/10 (9h-12h30)** - Exam

Principles in tissue engineering

Instructor in charge: Laurent Corté (laurent.corte@minesparis.psl.eu)
Year: M2 only
ECTS: 3
Format: 6 x 3h classes + EXAM
Language: English

When: Wednesday morning (subjected to changes)
Where: Arts et Métiers ParisTech, 151 Boulevard de l'Hopital, 75013 Paris

******* This class is part of the BME Paris master and **availability is VERY limited.** It is **mandatory to have followed the course* Fundamentals in biomaterials science** *to attend this course* ******

These lectures will provide an advanced introduction to the current developments in tissue engineering and in particular to the design of biomaterials for regenerative medicine. A first series of lectures focuses on the scientific and technical concepts involved in tissue engineering (regeneration vs repair, controlled degradation, angiogenesis, scaffold processing…). It is followed by seminars and debates with researchers currently working on nanotechnology, cell sheets and stem cells, applied to tissue engineering approaches. In a last lecture/seminar, researchers and clinicians are invited to present the detailed development of one tissue engineered product (cartilage, heart tissue…). In parallel to these classes, students in small groups choose a tissue/organ of interest and prepare a case study on how tissue engineering approaches could apply to their system.

2023-2024 Provisional Program

- **Fri. 03/11 (9h-12h30)** - General introduction to Tissue Engineering (regeneration vs repair, current uses, challenges and perspectives) (L.Corté, Mines Paris)
- **Wed. 15/11 (9h-12h30)** - Design principles for TE scaffolds (degradation kinetics, angiogenesis, nutrient and cell transport…) (L.Corté, Mines Paris)
- **Wed. 22/11 (9h-12h30)** - Materials and processing methods for TE scaffolds (decellularization, cellular and acellular approaches, bioprocessing) (L.Corté, Mines Paris)
- **Wed. 29/11 (9h-12h30)** - Use and manipulation of stem cells (W.Habeler, I-Stem)
- **Wed. 06/12 (9h-12h30)** - Cell sheets and nanotechnology for TE (S.Mozafari, U.Paris Cité)
- **Wed. 14/12 (9h-12h30)** - Scaffold functionalization strategies (T. Simon Yarza, LVTS)
- **Wed. 10/01/2024 (9h-12h30)** - Exam

External **Courses**
M1 only

Scientific Communication

Instructor in charge: Fabien Ferrage (fabien.ferrage@ens.fr)
Co-instructor: Mathilde Lepoitevin
Year: M1 only
ECTS: 3
Format: 20 h
Language: English

When: First lecture on Sept. 7, 2-4 pm, lectures on some Tuesdays afternoon, from week starting on Sept. 7 to jan. 18; see the calendar on Sept. 7, exam probably on Jan 25
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

NB: LIMITED to 20 STUDENTS

It is essential to communicate the results of your work well. Most of the time, this communication must be done in English. Why is a project important? What are the main results? What prospects do these results open up? Using as an example two central communication activities for the researcher: writing articles and designing oral presentations, we address many general communication principles. We study the structure of an article on several scales: its general organization, how to write a summary, how to structure a paragraph. We also pay great attention to the vocabulary and mistakes not to be made in English. For oral presentations, we work on how to design a slide, the rhythm, the way to express yourself.

The activities all take place in groups of two or three students. In written form, we do some exercises such as writing an article summary, then the focus of the work is on writing a short article based on unpublished results (usually an internship report). The groups work together, correct each other, in order to create, in a few sessions, a short but very good quality text. Oral communication involves a "pecha kucha" exercise, which forces you to simplify the slides and organize your speech. A training by a theatre teacher allows everyone to become an actor in their presentation. A 10-minute presentation is then prepared and repeated several times before a final session in front of a small audience of researchers and students.

Organic Chemistry I

Instructor in charge: Jean-Bernard Baudin (jean-bernard.baudin@ens.fr)
Year: M1 only
ECTS: 6
Format: 14 · 3 hour-lectures
Language: French only

When: Wednesdays mornings, from mid-Sept. to mid-January @ 8:45-12:00

Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This organic chemistry course builds on knowledge acquired in L1/L2 and wishes to be a rational study of the major reaction mechanisms of organic chemistry. These mechanisms are discussed based on the frontier orbital method. We analyze the four major processes (substitution, addition, elimination, transfer) and examine their essential characteristics. A crossing of the major mechanisms (ionic, radical and concerted) allows to show the fruitfulness of this approach, an examination of reaction intermediates most frequently encountered (carbocations, carbanions, radicals, carbenes) complete the presentation of relation between microscopic and macroscopic levels for condensed molecular phases.

1. Introduction: course objectives, historical background.

2. General Organization of organic reactions
Classifications (intermediate processes).
Frontier orbitals: principle, classification mechanisms; boundary model.

3. Stereochemistry and conformational analysis
Ethane, butane, cyclohexane, propene, cyclohexene, decalin, cycles C3 to C12.
Stereoelectronic effects: effects on equilibria and reactions.

4. Ionic reactions
Aliphatic nucleophilic substitutions: Ingold and Winstein models, solvation phenomena, phenomena of participation.
Electrophilic and nucleophilic additions.
Addition-elimination process (SEAr, SNAr), reactions on esters and derivatives.

5. Radical reactions and specific intermediates
Structure and production of radicals, orbital frontier method.
Main reactions: additions, substitutions.
Carbenes and nitrenes: structure, preparations, reactions.

6. Pericyclic reactions
Correlation diagrams, Woodward-Hoffmann rules, frontier orbital method.
Electrocyclization; sigmatropic rearrangements, cycloadditions.

Organic Chemistry II

Instructor in charge: Roba Moumné
Year: M1 only
ECTS: 6
Format: 12 · 3 hour-lectures
Language: French only

When: Wednesday morning, @ 8:45-12:00 from Feb. to June

Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This course aims to improve and refine the knowledge in Organic Chemistry acquired during previous semesters. The program addresses the reactivity of new classes of molecules as well as the study of some major reactions of organic chemistry. Carbon-carbon bond formation by reaction of a carbonyl is a central point of the unit. The notions of chemo-, regio- and stereoselectivity, as well as the application in synthesis of the methods treated will be addressed in particular. Prerequisites: A reasonable knowledge of Organic Chemistry from previous semesters.

1. Carbanions and carbon nucleophiles

2. Alkylation of carbon nucleophiles

3. Reactions of carbon nucleophiles on carbonyl groups

4. Transpositions and fragmentations

5. Radical chemistry

6. Chemistry of Carbenes and Nitrenes

Inorganic Chemistry I

Instructor in charge: Alice Balfourier
Year: M1 only
ECTS: 6
Format: 14 · 3 hour-lectures
Language: French only

When: Second semester — Tuesdays starting on Feb @ 8:45-12:00

Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

Cette UE présente les bases d'une culture générale en chimie inorganique moléculaire, avec une approche intégrée de la chimie de coordination et de la chimie organométallique. Les exemples seront choisis pour montrer comment les complexes peuvent répondre aux grands enjeux sociaux-économiques : conversion de l'énergie solaire, catalyse et chimie verte, imagerie médicale et thérapie, matériaux moléculaires… Elle est organisée en quatre grands chapitres abordant les thématiques/notions suivantes :

1- Notion de complexe en chimie inorganique : ligands usuels, ligands carbonés (complexes carbonyle, complexes pi), stabilité des complexes (effet chelate et macrocyclique, théorie HSAB)

2- Interaction métal-ligand (modèle du champ cristallin, utilisation des diagrammes d'orbitales moléculaires), règle des 18 électrons, exaltation d'acidité et activation du ligand

3- Réactivité : Réactions de substitution, de transfert d'électrons, réactions des ligands coordinés, grandes classes de réactions en chimie organométallique, application à quelques cycles catalytiques simples

4- Complexes polynucléaires : effet template, liaison métal-métal et clusters organométalliques.

Cinétique et réactivité

Instructor in charge: Damien Laage
Year: M1 only
ECTS: 4
Format: 14 · 3 hour-lectures
Language: French only

When: Second semester, Tuesdays starting on Feb, 1pm45-5pm.

Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

Ce cours explore la notion de mécanisme réactionnel sous ses différents aspects, du macroscopique au microscopique :

1. Le mécanisme réactionnel : un modèle simple pour une transformation complexe.
2. Potentiel chimique et structure moléculaire.
3. Des outils pour l'analyse mécanistique (techniques expérimentales, effets de solvant, effets isotopiques, relations d'énergie libre...).
4. Théorie de l'état de transition et constante cinétique de réaction ; coordonnée réactionnelle (illustration par des réactions de transfert d'atome en phase gazeuse).
5. Cinétique des réactions unimoléculaires.
6. Effets de solvant sur la constante cinétique de réaction. Réactions de type SN1 et SN2, transfert d'électron et transfert de proton en solution.

Thermodynamique statistique

Instructor in charge: François Xavier COUDERT
Year: M1 only
ECTS: 6
Format: 14 · 3 hour-lectures
Language: **French only**

When: First semester, Thursday 8am45-12am from mid-Sept. to mid-Jan

Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

Cet enseignement étudie l'effet des forces intermoléculaires sur la stabilité et l'existence de structures moléculaires variées. Nous explorons le champ de ces effets au travers de curiosités et de phénomènes issus de l'observation du monde physico-chimique et bio-chimique. Le contenu de ce module est donc abordé en considérant l'objet et en introduisant le formalisme nécessaire à son étude.

Programme

1. Notion d'ensemble statistique — L'ensemble canonique — Autres ensembles
2. Application aux systèmes « dilués » — Statistique de Boltzmann
3. L'approximation classique
4. Thermodynamique statistique des états de la matière moléculaire.
5. Approche analytique
6. Approche numérique
7. Introduction aux méthodes de simulation moléculaire

Bibliographie

Donald A. McQuarrie, *Statistical Mechanics*, Harper Collins Publisher, ISBN 06-044369-9 Chapitres 1, 2, 3, et 5.
R. Gaboriaud et coll., *Thermodynamique appliquée à la chimie des solutions*, Ellipses Chapitres VII, VIII et IX, pour les mélanges, écarts à l'idéalité.
H. H. Girault, *Électrochimie physique et analytique*, Presses polytechniques et universitaires romande (Chapitres 3, 4 et 5 pour les solutions ioniques et le transport dans ces systèmes)
P. Atkins et coll., *Chimie Physique*, Ed. De Boeck

Physico Chimie Analytique pour la bioanalyse et l'environnement

Instructor in charge: Anne Varenne (anne.varenne@chimieparistech.psl.eu)
Year: M1
ECTS: 2
Format: Lecture
Language: courses in French, project based on a discussion that can be in English

When: Fridays from **first week of September** till January
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

Les enseignements théoriques permettent d'aborder les méthodologies primordiales dans tous les domaines nécessitant du contrôle et de l'analyse, permettant l'accès à des informations quantitatives et d'interactions en solutions. Il s'agit essentiellement des méthodes séparatives et électroanalytiques, sous forme classique ou miniaturisée. Les aspects de séparation, de traitement de l'échantillon, de couplage des méthodes séparatives avec des méthodes de détection sensibles et spécifiques (fluorescence, spectrométrie de masse…) sont ainsi abordés. De plus, la thématique « contrôle de qualité » est présentée, incluant les normes, la traçabilité et l'analyse du cycle de vie. Il est en effet de plus en plus demandé à l'ingénieur de contrôler la pureté et la stabilité d'un produit par des méthodes traçables (traçabilité analytique des mesures, validation d'une méthode, échantillonnage, étalonnage, méthodes statistiques, rapport et archivage, réglementation, essais d'aptitude), en vue de leur accréditation par les normes en vigueur, qui se situent maintenant à un niveau international. Dans le cadre du développement durable, l'analyse du cycle de vie (ou écobilan) des produits est présentée.
Le module est constitué d'un travail sur projet (6 à 7 étudiants par projet) avec appui d'un support d'enseignements théoriques mis en ligne et de conférences faites par des spécialistes de différents domaines. L'objectif de ce projet est de trouver dans la littérature scientifique des méthodes (électrochimique, chromatographique et électrophorétiques) permettant d'effectuer la quantification de traces/ultratraces (impuretés de synthèse, polluants, biomolécules à application pharmaceutique…) dans des matrices complexes, définis par le projet. Les différentes méthodes sélectionnées seront comparées en termes de qualité de précision, facilité d'analyse, etc… et un choix sera fait sur la méthode la plus adéquate.

Objectifs d'apprentissage :
L'objectif de ce module est d'obtenir une vision complète et critique des différentes méthodologies d'analyse de traces voire ultra-traces dans des matrices complexes (biologiques ou environnementales). L'étudiant doit trouver, analyser et critiquer la bibliographie existante dans le domaine proposé, puis s'aider de ses connaissances pour sélectionner la méthode la plus adéquate voire être force de proposition pour imaginer une méthodologie nouvelle. Toutes les étapes d'une méthode d'analyse sont étudiées (prélèvement, traitement, séparation, détection).

Pré-requis : Notions issues des cours de chimie des solutions, méthodes séparatives, électrochimie, physico-chimie aux interfaces

Fundamentals of Biochemistry

Instructor in charge: O. Ploux (olivier.ploux@chimieparistech.psl.eu)
Year: M1
ECTS: 2
Format: Lecture
Language: **French only**

When: From early September to November
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

Le but de cet enseignement sera de donner aux étudiants les bases fondamentales pour comprendre le fonctionnement moléculaire des organismes vivants, c'est-à-dire de la biologie moléculaire (dans le sens large). Seront présentées la structure et la fonction des macromolécules biologiques (protéines, acides nucléiques, sucres et lipides) et seront abordés d'un point de vue moléculaire les grands principes de la biologie : flux d'information, évolution…

Program 2022-2023

DATE	Horaire	N° COURS	TYPE COURS SALLE
02-sept	15h15-16h45	BIO 1	CM AMPHI
13-sept	8h30-10h00	BIO 2	CM AMPHI
14-sept	10h15-11h45	BIO 3	CM AMPHI
19-sept	8h30-10h00	BIO 4	CM AMPHI
21-sept	13h30-15h00	BIO 5	CM AMPHI
04-oct	8h30-10h00	BIO 6	CM AMPHI
05-oct	13h30-15h00	BIO 7	CM AMPHI
07-oct	8h30-10h00	BIO 8	CM AMPHI
10-oct	8h30-10h00	BIO 9	CM AMPHI
18-oct	10h15-11h45	BIO 10	CM AMPHI
19-oct	15h15-16h45	BIO 11	CM AMPHI
21-oct	15h15-16h45	BIO 12	TD 4 SALLES
08-nov	8h30-10h00	BIO 13	TD 4 SALLES
09-nov	13h30-15h00	BIO 14	TD 4 SALLES
22-nov	8h30-10h00	BIO 15	TD 4 SALLES
28-nov	10h15-11h45	EXAM BIO	EXAM AMPHI

Biologie Cellulaire I

Instructor in charge: Andrea Dumoulin (andrea.dumoulin@ens.fr)
Year: M1 only
ECTS: 6
Format: 14 x 2.5 h lectures
Language: **French only**

When: Friday mornings, 9:30-12 am, from Feb. to May,
Where: Department of biology of ENS, 46 rue d'Ulm, 75005 Paris, room 316

L'objectif de ce module est d'apporter des connaissances nouvelles à des étudiants ayant déjà des bases, à travers deux types d'enseignements. D'une part le travail personnel qui aboutit à des présentations orales devant la classe ; ce travail est centré sur la diversité des voies de signalisation cellulaire.

D'autre part, est programmée une série de cours-séminaires assurés par des chercheurs, qui sensibilisent les étudiants aux aléas de la recherche et à la transmission des connaissances depuis la perspective d'un chercheur. Les sujets abordés sont : cytosquelette, cycle cellulaire, cancer et transduction du signal, organisation du noyau, apoptose, ainsi qu'un cours théorique introductif sur les différentes techniques de la microscopie optique actuelle.

Prérequis : BCPST ou L2 Sciences de la Vie, Médecine, etc. Il n'est pas ouvert aux étudiants n'ayant aucune base en biologie.

Molecular Biology & Genetics

Instructor in charge: Gersende Lepère (gersende.lepere@ens.fr)
Year: M1 only
ECTS: 6
Format: 13 x 3h lectures
Language: **French only**

When: Thursdays mornings (9 am-12 pm), from beginning of October to mid-January
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris, level 3

This course is designed to provide very solid bases in the fields of Molecular Biology and Genetics. Genetics is taught as a central axis of the biology of the heredity of phenotypes, as well as a methodology for studying biological processes in the laboratory.

The Molecular Biology part will cover the genome, its replication and reparation, and genetic expression and its control, in particular. Various methodologies of Molecular Biology and of genome editing will be also treated.

Program :

- Génétique-1 **Gersende Lepère**
- Génétique-2 **Gersende Lepère**
- Génétique-3 **Gersende Lepère**
- Focus sur le génome-1 **Denis Thieffry**
- Focus sur le génome-2 **Denis Thieffry**
- Contrôle de l'expression génétique-1 **Barbara Despres**
- Contrôle de l'expression génétique-2 **Denis Thieffry**
- Contrôle de l'expression génétique-3 **Barbara Despres**
- Contrôle de l'expression génétique-4 **Barbara Despres**
- Génétique Inverse **Patrick Charnay**
- Réplication, réparation, recombinaison-1 **Olivier Hyrien**
- Réplication, réparation, recombinaison-2 **Olivier Hyrien**
- Génétique-4 Génétique Quantitative **Henrique Teotonio**

Analytical and Biological Chemistry (ABC)

Instructor in charge: Fanny d'Orlye (fanny.dorlye@chimieparistech.psl.eu)
Year: M1 or M2
ECTS: 8 (***including four 2 ECTS-courses that can be taken individually***)
Format: Lectures and experimental visits
Language: English

When: **Second semester** – see below
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

Chemists and chemical engineers are more and more concerned with analytical and biological challenges in an increasing variety of research areas. This block courses therefore aims to give a basic overview of different aspects of analytical and biological chemistry without going into much details. The students will therefore be taught about novel developments and trends in modern bioanalytical chemistry, medical imaging, bioinorganic chemistry or biorefinery. The clear goal is to give students with a general background to meet these new challenges.

Prerequisite: basic knowledge of organic, polymer, analytical and inorganic chemistry, biochemistry (DNA, amino-acids, proteins, sugars, polysaccharides), as well as of material science with the atom energy levels.

This course will be divided into four courses, namely 1) Bioinorganic Chemistry; 2) Basic Concepts of Cell Biology, Microbiology, Protein Technology and Toxicology; 3) Modern Analytical Chemistry for Biotechnology and Clinical Diagnostics; 4) Chemistry Probes for Bioimaging.

1- Bioinorganic Chemistry— Medicinal Inorganic Chemistry

The vast majority of drugs used today are purely "organic" compounds – they do not contain any metal atoms. However, due to their different kinetic, geometric and electronic properties, metal complexes can undergo reactions, which are not possible with organic agents. With the exception of cisplatin and its derivatives, metal-containing drugs, particularly organometallics, have been, until very recently, largely neglected by both the pharmaceutical industry and academia. Over the last few years, however, things have changed, and significantly! Indeed, "inorganic drug candidates" are beginning to enter clinical trials, with more promising lead structures in the pipeline.

This course will cover the latest advances in the field of medicinal inorganic chemistry with an emphasis on the discovery of new inorganic compounds with proven anti-cancer activity, enzyme inhibition or anti-malarial properties. Moreover, the specific mechanism of action of the metal-based drugs will be presented in detail.

2- Basic Concepts of Cellular Biology and Enzymology

Provisional Program 2021-2022 is described below, please contact the instructor in charge (Pr. Michel Minier, michel.minier@chimieparistech.psl.eu) for updates

Presentation

Chemists and chemical engineers are more and more concerned with biology in an increasing variety of areas. If pharmacy and medicine combine these sciences for a long time, more recent issues are rapidly rising : for example biorefinery which aims to develop bio-sourced chemicals, fuels and materials, cosmetic industries looking for “natural, sustainable and safe” ingredients, environment protection through the development of non-toxic and biodegradable substances, water treatment, corrosion phenomena, bio-hydrometallurgy … It seems thus essential to teach the basic knowledge on cell structure, physiology, microbiology, protein biochemistry and toxicology to prepare our students to meet these new challenges.

Program

The course will be divided in four main sections. Cell biology, microbiology, protein technology and toxicology.

The structure, internal composition and basic concepts of physiology for typical living cells will be presented, in order to clarify the shared features and the differences between bacteria, yeasts, microalgae, archaea, vegetal cells … Some characteristics of viruses will also be discussed. Examples of industrial applications will be pointed out as much as possible.

The basic principles of mammal physiology will also be described, particularly the main different cell types and their role in the body function.

The criteria that govern the choice of instrumental techniques for the analysis of biomolecules, such as proteins and DNA, differ from those applicable to classical analytical chemistry. The purpose of the lectures is to present the basic principles and the applications of instrumental and molecular methods used for the analysis of biomolecules.

Toxicology starts with the knowledge of the basic biological mechanisms involved when a toxic (toxin, medicine, etc…) is absorbed by the organism. More precisely, the purpose of these courses is to give an overview of the ADME process (Absorption, Distribution, Metabolism, Excretion) in human body.

3- Modern analytical chemistry for biotechnology and medical diagnostics

Provisional Program 2021-2022 is described below, please contact the instructor in charge (Dr. Fanny d’Orlyé, fanny.dorlye@chimieparistech.psl.eu) for updates

When: Tuesday mornings from January to March

The developments and trends in modern analytical chemistry are going toward process simplification, automation and miniaturization while preserving the performance and reliability of analytical results. Possibilities and difficulties inherent to miniaturization at each step of an entire analytical process are quite different and should be addressed.

Thus, the course will focus on new analytical and bioanalytical tools allowing the downsizing of several laboratory functions (sample introduction, treatment, separation, detection) to handle extremely small fluid volumes but also to integrate aforementioned lab processes on a miniaturized device of a few square centimeters to achieve automation and high-throughput screening.

The main topics of concern are:

1) Basic microfluidic concepts

2) Innovative materials, microfabrication processes and surface modification strategies for microfluidic chip conception;

3) New functionalized nanomaterials for diagnosis: nano-supports (nanoparticles, nanotubes, monoliths, molecular imprinted materials …), selective agents (antibodies/proteins, aptamers, chelating agents…) and conjugation procedures;

4) Developments in miniaturized separation methods (chromatographic or electrokinetic) mainly based on molecular recognition to purify, concentrate and isolate analytes of interest;

5) Detection in miniaturized analytical systems (optical, electrochemical, mass spectrometry);

6) Analytical applications on going from standard bioassays to organ on chips, micro(nano)sensors and µTAS for biotechnology and medical diagnostic applications.

Applications will be treated in the context of biotechnology and clinical diagnostics, ongoing from standard bioassays to Micro Total Analysis Systems (µTAS), through seminars as well as project- and problem-based learning. The proposed pedagogical pattern requires the mandatory presence of all students. Any specific adaptation of the timetable requires the consultation of both the instructor in charge (Dr. Fanny d'Orlyé) and the coordinator of the Master's program.

4- Chemical probes for Bioimaging

Provisional Program 2021-2022 is described below, please contact the instructor in charge (Dr. Bich-Thuy Doan, bich-thuy.doan@chimieparistech.psl.eu) for updates

When: Monday mornings from January to March (amphitheater Moissan).

The field of medical imaging has become a real specialty and advanced research in the chemistry in relation to this biomedical domain is suited to the activities of academic, clinical and industrial laboratories. The development of this discipline is closely linked to the active development in current research area of new imaging probes to study pathological biological tissue for diagnosis or therapy with nanomedecine or targeted therapy guided by imaging, named theranostics. This diagnosis is evaluated in vitro, in vivo in preclinical to clinical studies and associated with industrial production of the novel imaging probes.

The main goal of this course is to provide to chemist engineer students a general overview of the commercial and innovative imaging probes designed for bioimaging for image guided diagnosis, i.e

- the multimodal overview in MRI, optics, X-rays, PET, ultrasounds imaging probes
- their molecular or nanoparticular characteristics,
- how they can be synthetized
- how they can be used through their applications in vitro and in vivo in the biomedical or medical field to the diagnosis of cancer, inflammation.
- and to the evaluation and development of innovative treatment.

The course will be divided into general courses including exercises, a case study and a bioimaging facility visit as practical course.

Imaging probes chemistry used in the main modern bioimaging modalities will be taught by chemists or biophysician teachers among the researchers of PSL and Paris from academic and pharmaceutical lab, with expertise in the respective imaging domains: Ultrasounds, Magnetic Resonance, Nuclear medicine, Optics, Xrays, Nanoparticular agents, Theranostic (imaging agent + drug) probes.

Statistical Learning

Instructors in charge: Yacine Oussar, Isabelle Rivals
Year: M1 or M2
ECTS: 3
Format: 30h Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
The objective of the course **Statistics and Modeling** (SL-SM) is to provide students with methods for adjusting and validating a linear model according to its parameters, as well as those adapted to nonlinear models, whether physical or behavioral models (such as neural networks), frequently used by engineers and researchers.

The purpose of the course **Machine Learning** (SL-ML) is to introduce students to theoretical and algorithmic notions to help them understand the current enthusiasm for statistical learning relying on big data. The course will refer to concepts from the course Applied Statistical Physics (S6-PSA) and will present applications in different fields, including biology; no prerequisite knowledge is required.

Prerequisites
Statistics, linear algebra

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Soft Matter

Instructors in charge: Jérôme Bibette, Michel Cloître
Year: M1 or M2
ECTS: 3
Format: 36h Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
Soft Matter refers to a set of materials that ranges from plastics to liquid crystals and includes gels, colloid pastes, surfactant solutions, biopolymers, foams, and more. These materials have the ability to easily deform and react to low physical or chemical stresses. This property derives from interaction forces whose amplitude is generally comparable to that of Brownian forces. Entropy also plays a key role. Competition between enthalpic forces and entropic forces is responsible for self-assembly phenomena that lead to fascinating structures involving a whole hierarchy of scales of length and time.
These materials form the basis of a multitude of technical industrial products and commodities. Polymer blends and block copolymers are the basis of high-performance plastics, recyclable elastomers, barrier films for packaging, adhesives, and more. Our screens and display devices contain liquid crystals that can be directed through the simple application of an electric field. Formulas for paints, printing inks, and cosmetics use combinations of surfactant molecules, colloids, and polymers that achieve the required physicochemical properties in low concentrations.

The course **Soft Matter and Development** (SoM-SMD), intended for physicists, chemists, and physical chemists, illustrates how a good knowledge of the basic concepts in soft matter, a firmly interdisciplinary approach, as well as a lot of imagination, support the design and development of innovative materials and processes.

The course **Colloids and Biomolecules** (SoM-CB) addresses the dynamics and microscopic behavior of colloids and, more particularly, bioactive colloids such as proteins, enzymes, and antibodies. The first three sections are theoretical and provide methods to rationalize and model the systems in interaction, taking into account specificity and catalysis. The last section describes how the evolution of colloid science has been used to design a range of innovations, from 20th-century diagnostic health devices to the latest discoveries and strategies currently being developed by start-ups.

Prerequisites
Diffusion, chemical kinetics

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Analytical Chemistry

Instructors in charge: Valérie Pichon, Jérôme Vial
Year: M1 or M2
ECTS: 3
Format: 30h Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
This purpose of this UE is to provide students with advanced concepts in analytical chemistry, particularly in the field of liquid chromatography and its use with mass spectrometry, alternative or complementary methods using biological or biomimetic tools, miniaturization of analytical tools, and chemometrics.
Bioanalysis can be defined as the analysis of compounds (drugs, doping agents, pollutants, etc.) in biological samples (biological fluids, tissues, etc.), or a field in which the coupling of liquid chromatography with mass spectrometry (LC/MS) is now essential. Bioanalysis can also be used to describe any analytical method based on the use of biological tools (antibodies, DNA strands, etc.) to improve the potential of conventional analytical approaches.

The course **Bioanalytics and Miniaturization** (ANC-BMMS) presents recent developments in chromatography and related techniques to improve their separation power and evolve towards ultra-fast analyses with high separation power. High-pressure and multidimensional chromatography, LC/MS coupling, selective biological and biomimetic tools for sample processing, and bioassays applied to the analysis of trace compounds in complex samples will be addressed. Emphasis will also be placed on the miniaturization of these analytical devices for lab-on-a-chip development.

The course **Chemometrics** (ANC-CHE) aims to give students the mathematical and statistical tools necessary to rationally construct experiments and achieve optimal use of the results. Students will also be exposed to the notion of uncertainty and trained in the tools used to identify and quantify the sources of variability in a process or method. Calibration issues will also be addressed from the user's point of view. Particular attention is paid to the relationships between statistical findings, their physico-chemical interpretation, and the practical consequences that arise from them.

Prerequisites
Applied Statistics, Analytical Sciences

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Interface Physics Biology

Instructors in charge: David Lacoste, Clément Nizak, Manuel Théry
Year: M1 or M2
ECTS: 3
Format: 33h Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
Our course describes the physico-chemical functioning of biological systems at different scales (molecular, cellular, multicellular), and then outlines the major scientific questions currently under study in the field of basic research and how theoretical and experimental concepts and tools from physics can address these questions. This course begins with a presentation of the orders of magnitude of key physical parameters for the description of living systems, and an introduction to the properties that distinguish them from inert matter. This comprehensive perspective will allow for an understanding of the multiple elements of the entire course and their connections.

A part of the course is dedicated to the experimental and theoretical design of artificial cells: synthetic objects made of lipids and proteins, animated by the physico-chemical principles that govern the functioning of cells. The course uses the cytoskeleton as a study system to address the main principles of the self-organization in cell biology and their practical implementation in the fabrication of these proto-cells. The course will describe the dynamics of intracellular architectures as well as methods to isolate components and orchestrate their interactions in simplified systems. It will explain the physico-chemical laws of self-organization of these components, the properties derived from them, and their description by Statistical Physics.
We will also discuss the contribution of the Physics of Big Data analysis applied to Biology. The rapid sequencing of genomes as well as other large-scale biology techniques produce large, high-dimensional data sets. Concepts and methods from Physics (especially Statistical Physics) can be used to extract interpretable information, and to understand the sequence-function relationship of proteins, the architecture of genetic networks or even genomes.
The constructive role of noise in Biology (stochasticity of biochemical networks and reactions, expression noise, noise in cell division, error threshold ...) will be analyzed theoretically. Another related question concerns the allocation by cells of their internal resources (energy, molecular building blocks) to basic cellular processes (such as DNA replication, protein synthesis…). Experimental phenomenological and modeling approaches have recently emerged to address this issue, referred to under the general term of cellular economy.

Prerequisites
Molecular Biology, Statistical Physics, Experimental Physics

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Chemical Biology and Molecular Biotechnology

Instructors in charge: Andrew Griffiths, Raphaël Rodriguez
Year: M1 or M2
ECTS: 3
Format: 26h Lectures, Tutorials
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
Chemical biology and molecular biology form a powerful collection of techniques to study biological systems at the organism's molecular and cellular levels. They are also powerful tools for discovering new targets for medications, developing new medications (small chemical molecules and large biopharmaceutical molecules), creating organisms and individual biomolecules (proteins and nucleic acids), processing information, and developing chemical circuits for industrial, diagnostic, and therapeutic applications. The unit's goal is to help students grasp the state of the art of research and technology in the field and its applications. Another goal is to illustrate how paradigm-changing technology development is often complex and interdisciplinary, combining, for example, next-generation sequencing, optics, nanomanufacturing, microfluidics, organic chemistry, molecular biology, and biocomputing. This knowledge will be applied to bibliographic projects during lab sessions.

Prerequisites
The following concepts are recommended, but will be briefly reviewed early in the course: molecular biology and organic chemistry

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Imaging

Instructors in charge: Charlie Demene, Gisella Vetere
Year: M1 or M2
ECTS: 3
Format: 30h Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
Understanding biological systems requires integrating an increasing amount of data between different organizational levels in a quantitative way. The purpose of the module **Biology and Neurobiology of Systems** (SBN) is to help students understand the current state of the art of research and implement tools for analysis and modeling across disciplines in the following areas:

- approaches drawing on statistical physics for analysis of biological complexity, including self-organization of molecular and cellular systems;
- population-level interactions, including cooperative systems, for example, the emergence of multi-cellularity;
- understanding brain function at a systemic level by linking behavior and neuronal activity.

These topics will enable students to address techniques ranging from DNA sequencing to in situ visualization of individual neuron activity, and mobilize advanced techniques for analyzing biological data. This knowledge will be applied in practical sessions through bibliographic projects and analysis of data extracted from the systems presented.

The course **Medical Imaging** (IMAG-MI) offers student-engineers tools to understand the issues and challenges of current research in medical imaging. More specifically, it enables them to gain an understanding of the physical mechanisms involved in the main clinical imaging methods; to define a general theory (direct problem-opposite problem) common to these methods that formalizes the notion of image reconstruction; to apply some of these image reconstructions to experimental data by themselves; and to identify the most prominent research topics currently being studied in imaging.

Prerequisites
The following elements are recommended but will be reintroduced at the beginning of the course: basic concepts of cellular and molecular biology (eg, replication, transcription, translation), brain anatomy and neuron function, Matlab programming basics, basic statistical concepts.

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Advanced Chemistry

Instructor in charge: Amandine Guérinot, Sandrine Ithurria, Christophe Meyer, Vanessa Pereira Pimenta
Year: M1 or M2
ECTS: 3
Format: Lectures
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
The UE Advanced Chemistry includes a mandatory core curriculum (20h):

- The course **Synthesis of Inorganic and Hybrid Materials** (AC-SIHM, 14h) is designed for chemists who wish to develop a broader vision of the synthesis and characterization of functional inorganic and hybrid materials.
  The course is comprised of two parts: Crystallized Inorganic Materials and Crystallized Porous Materials (7 hours each). For both classes of materials, the synthesis methods and the challenges related to their characterization will be addressed, as well as their potential applications in various fields (health, energy, environment, optoelectronics).
- The course **Synthetic Tools for the Science of Materials** (AC-STMS, 6h), included in molecular chemistry training, aims to provide students with in-depth knowledge about certain classes of essential transformations in materials chemistry such as click reactions, reversible reactions for dynamic covalent chemistry, and some applications of cross-coupling catalyzed by transition metals.

Students may then choose one of the following modules:

- The course **Synthesis of Functional Materials** (AC-FMS, 8h, two blocks of 4-hour lab sessions) will deepen their knowledge of synthesis in functional materials and their properties, in particular the synthesis of semiconducting nano-crystals and porous hybrid networks.
- The course **Advanced Selective Organic Synthesis** (AC-ASOS, 12h) will deepen, more specifically, their knowledge of selective organic synthesis while introducing them to asymmetric synthesis (diastereoselective and enantioselective reactions) - two areas of crucial importance, especially in medicinal chemistry.

Prerequisites
basic understanding of organic chemistry and solid-state chemistry, notions of coordination chemistry, reactivity profiles of major functional groups, classic transformations in organic synthesis (oxidation reactions, reduction and interconversion of functional groups)

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

Synthetic Chemistry and Applications

Instructors in charge: Amandine Guérinot, Christophe Meyer, Renaud Nicolaÿ
Year: M1 or M2
ECTS: 3
Format: 33h Lectures, group project
Language: English

When: **Second semester**
Where: ESPCI, 10 rue Vauquelin, 75005 Paris

Description
The purpose of the course **Polymer Chemistry and Applications** (SCA-PCA) is to introduce students to polymer applications by addressing both fundamental and application aspects. Particular emphasis is placed on the structure/property relationship and on designing complex macromolecular systems with a view to final targeted properties.
A wide range of fields are presented: porous polymer materials and their applications, molecular and macromolecular materials in organic electronics, dynamic covalent chemistry and its application for the design of polymer materials and formulations, the design and use of polymer nanoparticles in biomedical applications, olefin polymerization and catalysis, photopolymerization, and biopolymers.

The course **Molecular Chemistry Synthesis Methods** (SCA-SMMC) intends to show students that understanding the reactivity of organic compounds at the molecular level is essential to developing molecular architectures of diverse complexity, which can be applied to various fields (medicinal chemistry, agricultural chemistry, biology, materials science). The course will focus on the study of important chemoselective synthetic tools in organic chemistry and on fundamental transformations such as oxidation reactions, reduction reactions, functional group interconversion reactions, and reactions allowing the formation of carbon-carbon or carbon-heteroatom bonds. Applications in polymer chemistry, medicinal chemistry, and chemical biology will be presented.

Prerequisites
Basic knowledge of polymer chemistry and physical chemistry, organic chemistry, and inorganic chemistry. Students will need to know the reactivity profiles of the most important functional groups (alkenes, alkynes, carbonyl compounds, acid derivatives) and be able to write reasonable reaction mechanisms.

Detailed program in the Syllabus of 3rd year ESPCI engineer cursus

External **Courses**
M1 or M2

Data Analysis

Instructor in charge: Benoît Perez-Lamarque - benoit.perez@bio.ens.psl.eu, Emeline Perthame - emeline.perthame@pasteur.fr
Year: M1 or M2
ECTS: 3
Format: 30 h
Language: English

When: One week mid November 9-12 am and 2-5pm
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris

Please contact the instructor in charge before September for registration approval. This course is open to a limited number of students, with priority given to ENS students. Access to this course is not guaranteed.

Biological data are often complex and challenging to analyse due to non-normal distributions, nonlinear relationships, spatial/temporal structures and high dimensionality. This course will introduce the students to key concepts and statistical tools for the experimental design and analysis of biological data. After a brief refresher on basic elements of statistics, the students will be made familiar with hypothesis testing, univariate statistical tests (e.g. ANOVA), linear models, descriptive multivariate analyses such as Principal Component Analysis (PCA) and clustering. The course will alternate theoretical aspects and computer exercises on small datasets with the R Studio software. The students will be assigned a small project involving the different concepts and tools covered by the course.

Keywords: Statistical inference, linear regression, multivariate analyses (PCA, clustering)

Prerequisites: Basics in R programming and in statistics, e.g. random variables, discrete and continuous distributions, quantiles, etc.

Detailed program: https://www.enseignement.biologie.ens.fr/spip.php?article91

Suggested Readings:
Van Emden, H. (2012). Statistics for terrified biologists. John Wiley & Sons.
Crawley M.J. (2005) Statistics: An Introduction using R.
Holmes, S., Huber, W., & Martin, T. (2017). Modern statistics for modern biology [https://web.stanford.edu/class/bios221/book/]

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Epigenetics: from biological phenomena to molecular mechanism

Instructor in charge: V. Colot, B. Despres (Barbara.despres@ens.fr)
Year: M1 or M2
ECTS: 6
Format:
Language: English

When: January, the whole month (Mondays and Wednesday) (13 · 2 hrs classes)
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris, level 3

Please contact the instructor in charge in September for registration approval.

The objective of this course is to discover the paradigms of epigenetics: from the epigenetic phenomenoms to the molecular mechanisms. Topics include parental imprinting, X-inactivation in mammals, the hybrid dysgenesis in Drosophila, chromatin inheritance, non-Mendelian inheritance of genome rearrangements in Paramecium, paramutations and epimutations in plants, prions, cancer. This course is organised through seminars and analysis of articles.

Program 2022: https://www.enseignement.biologie.ens.fr/spip.php?article48

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Cell Biology II: traffic, motility, biophysics

Instructor in charge: Olivier COLLIN, Philippe CHAVRIER, Arnaud ECHARD and Chiara ZURZOLO.

Year: M1 or M2
ECTS: 6
Format: Research Seminars
Language: English

When: All Monday and Wednesday of September
Where: ENS Biology Department (IBENS), 46 rue d'Ulm

Please contact the instructor in charge before September for registration approval. Typical availability of 5 students.

This cell biology course will cover major topics of cell biology such as membrane trafficking, cytoskeleton organization, cell polarity establishment, cell cycle control and division, cell adhesion and migration. These cellular functions will be described in the context of normal or cancer cells. The course will also cover innovative biophysical approaches to cell biology including cellular bio-mechanics or micro-rheology. The course will be composed of a series of 2 hours research seminars and will be taught by a number of leading cell biologists from various research institutions including Institut Curie, Institut Jacques Monod or Institut Pasteur.

Prerequisites: Cell biology I (L3/BSc) or good background in cell biology (gene regulation, organization of prokaryotic and eukaryotic cells, signalling, etc).

Program: https://www.enseignement.biologie.ens.fr/spip.php?article59

Suggested readings :

- Molecular Biology of the Cell, Alberts (Garland Science Ed) ; Cell Biology, Pollard § Earnshaw (Saunders Ed)
- The Cell Cycle. Principles of control, D. Morgan (NSP Ed)
- Physical Biology of the Cell ; Phillips, Kondev & Theriot (Garland Science Ed)
- Optional : The biology of cancer, Weinberg (Garland Science Ed)

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Frontiers in microbial systems

Instructor in charge: Olivier Espéli (olivier.espeli@college-de-france.fr) and Guy Tran Van Nhieu, (ENS Paris Saclay) (guy.tran_van_nhieu@ens-cachan.fr)
Year: M1 or M2
ECTS: 3
Format:
Language: English

When: one week mid-November
Where: Collège de France, room D2, 11 place Marcelin Berthelot, 75005 Paris

Please contact the instructor in charge in September for registration approval.

Introduction to microbial systems for which the development of diverse and recent approaches (genome wide, single cell imaging, biophysical, modeling) has revealed key aspects of biology.

- Bacterial cell cycles and development
- Evolution and ecology of microorganisms
- Infectious diseases

The first day of the course will consist of a refresher course on the modern concepts of microbiology to allow the students of the different courses to better understand the lectures given by the guest professors. Then the course will feature 3 days, of three to four lectures by invited professors falling in the proposed themes, with one theme per day. One day will be dedicated to oral presentations of scientific articles by pairs of students, followed by questions. These presentations will be taken into consideration along with the participation during the week for the notation

Prerequisites: Basic knowledge in molecular and cellular biology (gene regulation, organization of prokaryotic and eukaryotic cells, signalling, etc).

Program: https://www.enseignement.biologie.ens.fr/spip.php?article158

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Optical microscopy: principles and applications

Instructor in charge: Laurent Bourdieu (laurent.bourdieu@bio.ens.psl.eu)
Year: M1 or M2
ECTS: 3 (theoretical only) or 6 (theoretical and practical sessions)
Format: Lecture
Language: English

When: 2 weeks late November, 1st week (course) 2nd week (practicals)
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris, level 3

Please contact the instructor in charge in September for registration approval.

Aims:
Through theoretical courses and hands-on sessions, the aim of this course is to teach the neuroscience student basic and advanced techniques in neuronal imaging and their application to the study of neuroscience.

Themes:
• Basics of optical microscopy
• Tools for imaging neuronal activity
• Two-photon confocal microscopy
• Super resolution optical microscopy
• Optogenetics
• Single molecule visualization
• Light sheet microscopy • Image analysis

Organization:
The course is organized over two weeks.
The first week is dedicated to lectures covering the principles of optical microscopy, and a range of classical and advanced techniques in microscopy and their applications in neurosciences.
The second week is dedicated to the hands-on workshops. It starts with a full-day session desassembling and assembling an upright microscope, before moving to sessions in small groups carried in research labs and directly related to the lectures of the first week (super-resolution, PALM-STORM, SPT, light-sheet imaging).

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Bioinorganic chemistry

Instructor in charge: Clotilde Policar (clotilde.policar@ens.psl.eu)
Year: M1 or M2
ECTS: 4
Format:
Language: English (if non-french speaking attendees)

When: Tuesday mornings, 8h30-12h45
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

The lecture will present recent advances in bio-inorganic chemistry. Dealing with fundamental thermodynamical and reactivity, key concepts in inorganic chemistry will be discussed on examples taken in biological systems in order to better understand how specific physico-chemical properties of metal cations are used by living systems. The lecture will describe endogenous metallic systems, mainly metalloproteins, but also inorganic artificial structures used in biology (as medecine, probes). It will also delineate how chemists can design bio-inspired metallic systems.

Tentative program:
Introduction: role of metal cations in biology ; metallic complexes and biomolecules
Hemoglobin and myoglobine: form biological function to artificial mimic molecules
Metalloproteins mechanisms: cyp450, Zn proteins, di-iron proteins.
Oxidative stress and protective metalloproteins
Imaging metal complexes

Prerequisite
This course requires basic notions in inorganic chemistry.

Inorganic spectroscopies

Instructor in charge: Antoine Tissot (antoine.tissot@ens.psl.eu)
Year: M1 or M2
ECTS: 2
Format: Lecture
Language: English (if non-french speaking attendees)

When: Tuesday mornings, 10pm45-12pm45 from Nov. to Jan.
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This lecture will concern electronic structure of transition metal complexes. Different spectroscopies, mainly UV-visible spectroscopy and electronic paramagnetic resonance, will be presented in this context. It will develop concepts introduced at the L3 level, in inorganic chemistry, spectroscopies, and theoretical chemistry (ligand field theory, molecular orbital theory, group theory for chemists, spectroscopic terms, selection rules).

Prerequisite
This course requires basic notions in inorganic chemistry. Ideally, some basic notions of group theory for chemists could be useful (To read basic text books in inorganic chemistry such about symmetry may be sufficient).

Nuclear Magnetic Resonance

Instructor in charge: Kong Ooi Tan (kongooi@mit.edu)
Year: M1 or M2
ECTS: 4
Format: 8 x 4 hour-lectures
Language: English

When: Wednesday afternoon, 2pm-6pm15, from early Sept. to end of Oct.
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This course offers a fundamental understanding of NMR spectroscopy, a widely applicable technique in the field of (bio)chemistry to study the structure and dynamics of interesting systems ranging from biomolecules, (in)organic molecules, etc. Analytical tools such as quantum mechanics and linear algebra will be used to help students build a solid foundation on the working principles of NMR pulse sequences, and how they can be exploited to extract useful information. A study tour will be arranged to visit the state-of-the-art DNP NMR spectrometers in our laboratory in the last week of the course. The achievement of these objectives is measurable by a written examination.

Course syllabus
1. Introduction to NMR: Boltzmann population; Density operators; Liouville-von Neumann equations; Spin interactions; Product-operator Formalism

2. Dynamics and Chemical Exchange; Solution-state biomolecular NMR; Introduction to MRI: Gradients; Contrast agent; Ernst angle; Selective pulses

3. Solid-state NMR: Spherical tensors; Powder spectra; Magic-angle spinning; Average Hamiltonian Theory

4. Recoupling sequences; Cross Polarization REDOR; Homonuclear and heteronuclear polarization transfer techniques; Spin Decoupling

5. Pathway towards structure determination of biomolecules: Assignment Strategy; Distance Restrains; Structure Calculations; Introduction to DNP

Prerequisite
It is highly recommended (although not necessary) that the students revisit the course materials/lectures of the basic NMR course taught by Dr. Fabien Ferrage before enrolling in this course. A basic understanding of linear algebra and quantum mechanics will be essential and also very helpful.

References
[1] J. Keeler, '*Understanding NMR Spectroscopy*', 2005, Wiley
[2] M. H. Levitt, '*Spin Dynamics: Basic of Nuclear Magnetic Resonance'*, 2001, Wiley

Advanced Magnetic Resonance (solid-state EPR and DNP NMR)

Instructor in charge: Kong Ooi Tan (kongooi@mit.edu)
Year: M1 or M2
ECTS: 2
Format: 8 x 2 hour-lectures
Language: English

When: Wednesday afternoon, 2pm-4pm, from mid-Nov to end of January, exam end of January.
Where: Department of Chemistry of ENS, 24 rue Lhomond, 75005 Paris

This course further extends the contents covered in the Nuclear Magnetic Resonance course taught by the same instructor. It will introduce the basic concept of EPR spectroscopy, and how it merges with NMR to give birth to a new field, dynamic nuclear polarization (DNP), which is an emerging and research-active topic. Latest development on the topic from literature (and also from our laboratory) will be discussed. The students will be assessed based on an oral examination and invited to give a presentation.

Course syllabus
1. CW & Pulsed EPR; EPR Hamiltonians; Instrumentation; ENDOR; DEER; ESEEM/ HYSCORE; EDNMR; Applications to biomolecules, i.e. RNR and fibrils

2. Principles of CW DNP mechanisms: Solid effect; Cross effect; Thermal mixing; Overhauser effect; Dissolution DNP; MAS DNP

3. Pulsed DNP; DNP Instrumentation; Microwave sources; Gyrotron; DNP Probe;

4. DNP Applications to biological macromolecules; membrane proteins; amyloid fibrils

Prerequisite
The students should have taken the NMR course taught by the same instructor (Kong Ooi Tan) before taking this course.

References
[1] A. Schweiger and G. Jeschke, ‘Principles of Pulse Electron Paramagnetic Resonance’, 2001, Oxford University Press
[2] Q. Z. Ni et al., ‘High Frequency Dynamic Nuclear Polarization’, 2013, 46, Accounts of Chemical Research.
[3] A. Lilly Thankamony et al., ‘Dynamic nuclear polarization for sensitivity enhancement in modern solid-state NMR’, 2017, 120-195, PNMRS

Microbiologie appliquée et bioprocédés

Instructor in charge: M. Minier (michel.minier@chimieparistech.psl.eu)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: French only

When: Tuesday Morning
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

Descriptif du cours :
Cet enseignement se propose de discuter les applications de la microbiologie aux bioprocédés. Les différents thèmes abordés par des conférenciers académiques et industriels sont :

- La technique des bioprocédés (culture, sélection, méthodes de suivi)
- Les différentes applications des cellules vivantes (microorganismes, cellules végétales ou animales, …) dans de nombreux secteurs : énergie, chimie fine, agroalimentaire, cosmétique, santé, environnement.

Cours : 34 h, TD : 2 h, TP : 4 h

Objectifs d'apprentissage :
L'étudiant a une compétence de base, complémentaire à sa formation de chimiste, dans les bioprocédés. Il sait comment mettre en place un réacteur pour des applications très variées dans le domaine de la chimie.

Pré-requis : niveau licence en chimie-physique

Magnetic resonance

Instructor in charge: Fabien Ferrage (fabien.ferrage@ens.psl.eu)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: English only

When: Tuesday morning
Where: ESPCI, Radium room

**** This class is part of the ICI-PSL Master Track ****

Prerequisites:

Basic mathematics (linear algebra, calculus: differential equations/integrals, Fourier transform)

Quantum mechanics: Dirac notation and algebra in Hilbert spaces, Pauli matrices, angular momentum operators and their properties

Electronic structure of molecules and coordination complexes, ligand, and crystal field theories

Basic classical physics: angular momentum, magnetic/electric dipole, and dipole-dipole interactions

Objectives:

Give chemists the foundations to understand magnetic resonance (MR) spectroscopies and how MR can be used in many fields in chemistry, physics, and biology.

Introduce MR spectroscopies (NMR and EPR) using a theoretical quantum mechanical framework

Give chemists a link between the observables of magnetic resonance and molecular structure, dynamics, molecular orbitals and other chemical properties.

Introduce the use of MR in various fields of research, ranging from materials, biological systems, cultural heritage, etc.

Faculty:

Laurent Binet (8 hrs); Jean-Baptiste d'Espinose (10 hrs); Fabien Ferrage (Coordinator; 12 hrs); Kong Ooi Tan (15 hrs)

Valorization of small molecules

Instructor in charge: Christian Serre (christian.serre@espci.fr)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: English only

When: Monday Afternoon
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

** *This class is part of the ICI-PSL Master Track* **

Prerequisites
Kinetics, electronic properties of solids, introduction to electrochemistry (redox reactions, Nernst potential, Tafel slopes etc.), basic organic chemistry knowledge, basics in coordination and organometallic chemistry (electronic structure of transition metal complexes, elementary steps in organometallic chemistry), basics on porous materials and their sorption properties.

Objectives
This set of courses ambitions to give the students a general overview about the state of the art and current challenges in the field of small molecules, from their capture to their catalytic transformation. The vast majority of existing courses focus either on sole gas storage or separation issues or alternatively discuss only their catalytic conversion (e.g. H_2 production, CO_2 reduction). To our knowledge, there is no master level formation that gathers both approaches. Both point of views are strongly related and complementary and most likely any major future breakthrough that will come out shall rely on such integrated approaches. In addition, instead of typically focusing on a specific catalytic transformation (e.g. electrochemical or photocatalytic, homogenous) or relying on a given class of catalysts (homogenous or heterogeneous, dense or porous materials, inorganic, hybrid or organic), a global overview of the field within pros and cons for each class of materials is proposed in order to enable students to possess a comprehensive and fair vision of this domain of major importance for the energy transition.

Teachers:
- Chimie Paris Tech: G. Lefèvre (CR CNRS)
- Collège de France: C. Mellot-Draznieks (DR CNRS), M. Fontecave (PR)
- ESPCI/ENS: G. Mouchaham (CR CNRS), C. Serre (DR CNRS)

Dynamic and Reconfigurable Polymers and Soft Materials

Instructor in charge: Yvette Tran (yvette.tran@espci.fr) and Renaud Nicolay (renaud.nicolay@espci.psl.eu)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: English only

When: Monday morning
Where: ESPCI, Radium room

****** *This class is part of the ICI-PSL Master Track* ******

Prerequisites:
Basics in polymer and soft matter: chemistry, physicochemical and mechanical properties, thermodynamics.

Objectives:
The objective of this course is to give students an overview of the engineering of dynamic and reconfigurable polymers in materials and biomimicry. We offer an interdisciplinary approach to soft matter and polymers: from molecular / macromolecular chemistry to physicochemical and mechanical properties.
The following systems and/or concepts will be covered:
● Synthesis, characterization and specific properties of dynamic covalent polymer networks
● Sequence-controlled and semi-crystalline polymers: organization, interfaces, specific properties
● Impact of the presence and spatial organization of dynamic bonds onto the properties and processing of dynamic covalent polymer networks
● Responsive polymers: gels and interfaces
● Light-responsive assemblies
● Soft materials based on thermotropic and lyotropic liquid crystal polymers

Faculty:
Costantino Creton (Part 3, 8 hrs); Min-Hui Li (Part 6, 8 hrs); Renaud Nicolaÿ (Part 1,10 hrs, coordinator), François Tournilhac (Part 2, 8 hrs), Christophe Tribet (part 5, 6 hrs); Yvette Tran (Part 4, 8 hrs, coordinator)

Evaluation:
Project of students
Analysis and discussion of research articles and/or experimental data

Coupling analytical techniques for in operando monitoring of local events

Instructor in charge: Fethi Bedioui (fethi.bedioui@chimieparistech.psl.eu)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: English only

When: Wednesday afternoon
Where: Chimie Paris Tech, 11 Rue Pierre et Marie Curie, 75005 Paris

****** *This class is part of the ICI-PSL Master Track* ******

Prerequisite

It is necessary to know the basics and principles of the techniques that will be discussed and deepened. Also, general culture in the field of analytical techniques in chemistry, physics and chemistry, spectroscopy will be a plus. In particular:
- Know the basics of thermodynamics and electrochemical kinetics: electrode potential, current-tension curves, load transfer, material transport
- Know the principal forces and interactions that control the performances of separation method and how to evaluate these methods in terms of recovery rate, separation selectivity, concentration factor,
- Know the physical principles of NMR and optical spectroscopies.
- Know how a simple NMR experiment is performed.

Educational goals

The development of analytical methods is closely related to advances of complementary in-situ microscopies, spectroscopies, spectrometric techniques et.… Their combination provides a wealth of new information on structure changes, reaction pathways and local events determining and/or taking place during chemical or biological reactions. This course will gather contributions highlighting recent methodological and topical developments in the field and those predicted to be important in the near future. It will be composed of 4 parts of 12 h each, including one session of application (TD; 1,5 h) and one seminar (1,5h)

Databases and statistical learning for chemical discovery

Instructor in charge: François Xavier Coudert (fx.coudert@chimieparistech.psl.eu)
Year: M1 or M2
ECTS: 6
Format: Lecture
Language: English only

When: Friday afternoon
Where: ESPCI, Radium room

**** This class is part of the ICI-PSL Master Track ****

Prérequis : mathématiques de premier cycle (algèbre linéaire), formation M1 de chimie physique ; pas de prérequis stricts sur la chimie théorique, mais une formation M1 sera un plus.

Objectifs:

Repérer les types de données produites au cours d'une activité de recherche, les méta données associées et les enjeux de leur conservation

Connaître les principales bases de données existantes en chimie

Comprendre la méthode d'apprentissage statistique utilisée dans des travaux publiés, son mode de fonctionnement et ses limitations

Mettre en œuvre une méthode d'apprentissage statistique sur des données de chimie

Structure du cours :

Bases théoriques (16 h)

- Les données en chimie : méta données, stockage et curation, API
- Les bases de données existantes : matériaux, molécules ; théoriques, expérimentales ; structures, propriétés
- Fondamentaux de l'apprentissage statistique : machine learning, deep learning
- Données et reproductibilité , démarche open science

Cours-conférences sur les applications (16 h)

- Relations structure/propriété, structures/activité ; méthodes QSAR/QSPR
- Machine learning pour la chimie théorique : fonctionnelles, champs de forces réactifs, exploration et variables collectives, etc
- Criblage large échelle pour applications pharma, docking et méthodes avancées

Projets par binôme (16 h)

Intervenants : François-Xavier Coudert, Carlo Adamo, Damien Laage, Jérôme Hénin, Maximilien Levesque / Aqemia

Modalités d'évaluation :

50% sur un examen écrit, portant sur les bases et les applications

50% sur la présentation des résultats de leurs projets

External **Courses**
M2 only

Master 2 Chimie Paris Centre
Sorbonne Université – PSL Université

All courses from the other tracks of the **master Chimie Paris Centre** are available for M2 students. For registration contact mathieu.morel@sorbonne-universite.fr

Planning and details of the courses can be found in the panel “Unités d’enseignements de spécialisation M2S3” on the master website.

A selection is given below, with links to their descriptions (all courses are 6 ECTS)

Jour	Matin	Après-midi
Lundi		• 5Ci209 Modélisation multi-échelle des systèmes moléc. complexes • 5Ci409 Méthodologies innovantes pour une chimie durable
Mardi	• 5Ci605 Physico-chimie des polymères • 5Ci013 Material Surfaces at the BioInterfaces	• 5Ci203 Méthodes électrochimiques
Mercredi	• 5Ci407 Molecules, métalions and metal complexes (biology, medicine)	• 5Ci807 Bioprocédés
Jeudi	• 5Ci202 Chimie Analytique et Bioanalyse (II) • 5C602 Biomatériaux et matériaux pour le vivant	
Vendredi	• 5Ci809 Systèmes microfluidiques : principes et conception • 5Ci011 Management stratégique et entreprenariat	

Science et ingénierie des Matériaux pour la santé

Instructor in charge: Laurent Corté (laurent.corte@minesparis.psl.eu), Yannick Tillier (yannick.tillier@minesparis.psl.eu)
Year: M2
ECTS: 2
Format: 7 x 3h classes
Language: **French only**

When: from mid-October to mid-November (AM = 9:00 - 12:15, PM = 13:45 - 17:00)
Where: Mines Paris, 60 Boulevard Saint-Michel, 75006 Paris

***** The class is part of the 3rd year Mines engineering program. Course are in French with a limited number of students (about 3 seats available). Registration before end of September.*****

This class is a broad introduction to the design and development of materials for health related applications. A general presentation gives an overview of the main scientific and industrial challenges at stake. It is followed by a series of lectures and seminars focusing on the key concepts an engineer must know to work in the field of materials for health. For that, these concepts cover a wide range of questions related to the properties of living tissues, the selection and characterization of implantable materials, the biological response to these materials as well as the compatibility with clinical practice, regulatory issues, clinical validation and commercialization. These concepts are illustrated by different experts (researchers, surgeons, lawyers, engineers and managers) using examples taken from the implanted device industry.

In parallel to the lectures, students work in small groups and apply the concepts seen during the lectures to a system of interest. At the end of the lectures, they defend a project involving the design of an implantable material or device in front of a jury of experts.

Prerequisite
No particular prerequisite. Accessible to students with M2 level in engineering, physics, chemistry or biology.

Program

1- General introduction and key-concepts about living tissues and material-host interactions.
2- Mechanical properties of tissues, in vivo and in vitro characterization
3- Main classes of biomaterials (polymers, metals, ceramics)
4- Processing approaches for implantable materials
5- Material design and surgical practice
6- Regulatory aspects in medical device development
7- Technology transfer and commercialization of implantable devices

Cellular ecosystems: from modeling to medicine

Instructor in charge: F. Devaux (frederic.devaux@sorbonne-universite.fr)
Year: M2
ECTS: 3
Format: 30 h
Language: English

When: mid October full week
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris, level 3

Please contact the instructor in charge in September for registration agreement.

This course will present the applications of systems biology to topics related to human health. Several internationally renowned researchers will present their works aiming at providing integrative and/or quantitative views of complex human diseases, including cancer, obesity, immunity, etc…

Themes:
Transcriptomics of obesity
Modelling of immune system differentiation and functioning
Metagenomics of nutrition
Microfluidic devices for cancer research
Systemic approaches of oncogenesis
Tumor classifiers and cancer diagnosis
Genome-wide association studies and deep sequencing

Program 2022: **https://www.enseignement.biologie.ens.fr/spip.php?article97**

Register here : https://www.scolarite.enseignement.biologie.ens.fr

Molecular Neuropharmacology

Instructor in charge: Laetitia Mony (laetitia.mony@ens.fr)
Year: M2
ECTS: 3
Format: 20h courses + 3h paper presentations
Language: English

When: 1 week early January
Where: Department of Biology of ENS, 46 rue d'Ulm, 75005 Paris, level 3

Please contact the instructor in charge before September 15th for registering. Typical availability of 5 students.

This module is about neurotransmitter receptors and transporters, which are key actors of neuronal communication. The recent boom in membrane protein structures sheds a new light on our understanding of the function and the regulation mechanisms of these proteins. It also provides an unprecedented structural and conceptual framework to discover and develop new molecules of pharmacological interest. This module will tackle the molecular and structural organization, as well as the operating mechanisms of the main classes of neurotransmitter receptors and transporters. We will present their activation principles, as well as their interactions with ligands. Emphasis will be put on the allosteric mechanisms and subsequent conformational dynamics. We will also show how malfunction of these proteins can be at the origin of pathologies, making them targets of therapeutic interest. Finally, using concrete cases, this module will introduce students to the development process of new molecules of neurological and psychiatric interest.

It is organized as 8 courses lasting 2h30 plus one free afternoon dedicated to paper analysis and one afternoon of paper presentation.

Validation will consist of:

- Paper analysis and presentation (40 % of the grade). Students will choose a paper from a predefined list at the very beginning of the module week, analyze it during the course of the week and present it the last afternoon.
- Written exam (60 % of the grade). Written exam will take place the week after the module week, according to the students availabilities.

Register here : https://www.scolarite.enseignement.biologie.ens.fr