PSL UNIVERSITÉ PARIS

# MASTER
## MATERIALS SCIENCE AND ENGINEERING

## Joint course Master 1

## PRESENTATION OF THE MASTER

### The Master of Materials Science and Engineering from Paris Sciences et Lettres University (PSL-SGM)

The PSL Master "Materials Science and Engineering" allows students to acquire the experimental and theoretical knowledge necessary to imagine and design the materials of tomorrow, improve the performance of existing materials and predict their service life. Co-led by internationally renowned schools: Chimie ParisTech, MINES ParisTech and ESPCI Paris, it aims to establish the link between elaboration, synthesis and forming processes, (micro) structure and structural and/or functional properties of materials as varied like polymers, metal alloys, ceramics or biomaterials.

During the first year (M1) of the Master, students develop skills to have an integrative vision of materials with their functionalities in their environment, in their use and in their elaboration. This first year serves as a common base of knowledge to allow students to specialize in the second year (M2). Three tracks are offered for the second year:

- Track "Materials of the Future: Design and Engineering"
- Track "Mechanics of Materials for Engineering and Structural Integrity"
- Track "Microfluidics"

The experimental approach is particularly highlighted in this Master from the M1, with a training in research "through the practice of research", including literature review, 9 weeks of mandatory immersion in academic or industrial research laboratories, and hours of experimental work during the year of M1.

The M1 is fully taught in English.

### Objectives of the M1 training

During the two semesters of M1, students must acquire:

- Scientific knowledge allowing them to analyze a problem in a field related to the improvement of the performance and durability of a material in connection with its structure and chemistry.
- The experimental and theoretical knowledge necessary to imagine and design innovative materials that meet precise specifications and also to improve the performance of existing materials and predict their lifespan
- Methods of analysis of a scientific problem: information search and bibliography management; design of experimental protocols.
- Skills for presentation of scientific data and data interpretation (in English).
- The tools necessary for the development of industrial or academic research projects.

### Pedagogical and scientific tutoring

Scientific tutoring is an essential part of the training. From Master 1, each student benefits from a particular support by a doctoral student around a research project, with a first phase dedicated to learning bibliographic research in Semester 1, followed by a second phase of laboratory practice in Semester 2.

As many apprenticeships are offered in the form of projects in Master 1 and Master 2, a pedagogical tutoring to learn about team working is also present.

## ORGANIZATION OF TEACHING COURSES

### Duration of teaching courses

Semester 1: 249 hours over 15 weeks of common base, constituting two blocks of courses:

- One 121-hours block “Basic knowledge in Material Science” counting for 16 ECTS
- One block “Scientific tools and communication” counting for 14 ECTS

Semester 2 : From 162 to 188 hours of specialization courses, constituting two blocks of courses:

- One block "Specialization in Material science” from 74 to 100h counting for 12 ECTS
- One block “Scientific tools and communication” of 88h counting for 10 ECTS
- A minimum 2-months internship counting for 8 ECTS

The start of the school year will take place in early September 2022 at Chimie ParisTech, 11 rue Pierre et Marie Curie, 75005 Paris. The schedule will be communicated to students via their personal online access once they have registered.

Language courses are scheduled in the evening from 18:15 to 20:15.

# MASTER *MATERIALS SCIENCE AND ENGINEERING*

## Common Base: M1

### Master 1: Common Courses

The courses shown in italics are the mandatory courses. Courses written in normal style are optional courses. The language of teaching at the M1 level is English.

| **Semester 1 10 mandatory courses (30 ECTS)** | | **ECTS** |
|---|---|---|
| ***BASIC KNOWLEDGE IN MATERIAL SCIENCE*** | 128 h | 16 |
| *Corrosion* | 24 h | |
| *Physical properties of polymers* | 24 h | |
| *Crystalline materials* | 32 h | |
| *Metallic materials* | 24 h | |
| *Introduction to Mechanics* | 24 h | |
| *Electrochemistry (optional)* | 12 h | |
| **SCIENTIFIC TOOLS AND COMMUNICATION** | 121 h | 14 |
| *Programming* | 18h | |
| *Experimental methods* | 47h | |
| *Literature review: conducting and writing* | 9h | |
| *Innovation project (in group)* | 27h | |
| *Language courses* | 20h | |
| **Total S1** | 249h | 30 |
| **Semester 2 5 mandatory courses (13 ECTS) + 3 Uoptional courses to choose (9 ECTS) Internship of 2 months* (8 ECTS)** | | |
| ***Specialization in Material science*** | 92 - 118 h | 14 |
| *Modeling* | 18 h | |
| *Materials processing* | 24 h | |
| Electronic properties of solids | 24 h | |
| Inorganic assemblies | 18 h | |
| Surface properties and mechanical strength of materials | 24 h | |
| Advanced fluid mechanics | 30 h | |
| Solid Material Mechanics | 24 h | |
| From mechanical testing to constitutive law | 34 h | |
| **SCIENTIFIC TOOLS AND COMMUNICATION** | 85 h | 8 |
| *Language courses* | 30 h | |
| *Innovation Project (in group)* | 18 h | |
| *PSL week* | 37 h | |
| *Internship* | | 8 |
| **Total du S2** | 177 -203 h | 30 |
| **Total du M1** | 439 - 465 h | 60 |

** The duration of the traineeship indicated constitutes the minimum allowing validation. The internship can be done in France or abroad.*

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# Content of Teaching Modules

## M1COR : CORROSION

*Keywords:* Pourbaix diagram, passivation, generalized and localized corrosion

| | |
|---|---|
| Teachers | Cécilie Duhamel |
| Coordinator | cecilie.duhamel@mines-paristech.fr |

| *ECTS* | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 12 h | 12h | 3h | | 70% | 20% | 10% | | Yes |

***Description of the teaching module:***

The course focuses on aqueous corrosion of metals and metal alloys. First, the basic concepts of aqueous corrosion are presented: Pourbaix diagram, corrosion rate, passivity. These notions are then implemented to describe and explain the different forms of corrosion observed: uniform corrosion, galvanic coupling, localized corrosion.

Content:

- Definition and introduction to different forms of corrosion
- Electrochemical nature of corrosion
- Thermodynamic aspects: the Pourbaix diagram
- Corrosion rate: Butler-Volmer law, Tafel representation, reactions controlled by the transport of matter
- Passivation
- Uniform corrosion
- Localized corrosion: intergranular corrosion, pitting, cavernous corrosion,...

***Learning Objectives:***

At the end of this Training Module, students:

- Will be able to understand the fundamental aspects of electrochemistry
- Will be able to establish the equations of current-potential characteristics under equilibrium conditions
- Will know how to use a Pourbaix diagram
- Will be able to determine a corrosion rate
- Will be able to recognize different forms of corrosion

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | 12h course + 12h tutored exercises | English | English |

## M1POL : PHYSICO-CHEMISTRY OF POLYMERS

*Keywords: Polymers, glass transition, mechanics, thermodynamics*

| | |
|---|---|
| Teachers | Patrick Perrin, Joshua MacGraw |
| Coordinator | patrick.perrin@espci.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 13,5 h | 10,5h | 3h | | 100% | | | | no |

***Description ofthe teaching module:***

1. Conformation of chains
   - Ideal chains: Entropy of ideal chains; free energy; Hooke's law for polymers
   - Real chains : Flory solutions (concentration regimes), blobs -> concentrated solutions
2. Macroscopic consequences of random walk chains
   - Rubber elasticity : affine network model, modulus of a network
   - dynamics (Rouse, Zimm, Entanglement)
   - rheology (G', G'')
3. Thermodynamics of mixtures
   - Flory Huggins theory
   - Specification of concentrated and dilute regimes
4. Solid state properties, mechanical properties, glass transition
   - Tg, Tm, WLF, VF
   - time-temperature superposition
5. Characterization
   - Intrinsic viscosity
   - Light scattering
   - Size exclusion chromatography

***Learning Objectives:***

Students will be exposed to the basic principles governing polymer molecules and materials composed of these macromolecules. Starting from the characteristic dimension of monomers, and going through that of entire chains and networks thereof, along with polymer solutions and solid state materials, the students will acquire a basic knowledge of this important class of materials which are widespread in biology and industry.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | English | English | English/French |

## M1CRIST : CRYSTALLINE MATERIALS

*Keywords:* structure, diffraction, symmetry...

| | |
|---|---|
| Teachers | Vanessa Pimenta |
| Coordinator | vanessa.pimenta@espci.fr |

| ECTS | Course | Exercises | Practical | Tutoring | Written Exam | Continuous Eval. | Practical Exam | Oral Exam | Mixed Eval. |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 14 h | 14 h | 8h | | 100% | | | | non |

***Description of the teaching module:***

The aim of this course is to provide students basic tools to describe the structure and properties of crystalline materials. The course starts by the study of symmetries and the classification of crystals. Then, a detailed review of the investigations methods by X-ray diffraction is proposed. The last part of the course deals with the structures of ionic and covalent crystals as well as deviations from the perfect crystal, in order to understand the relationships between the structure of the main crystalline solids and their physical properties.

Content :

- Crystallography: periodic lattices - symmetry - point and space groups
- Radiocrystallography: reciprocal lattice - structural factor - structure resolutions - diffuse scattering - experimental methods
- Crystal structures: ionic and covalent crystal
- Point defects - extended defects - non-stoichiometry - ionic conductivity Disorder in crystals
- Quasi-crystals
- Structure-property relationships: Curie principle
- Piezoelectric and ferroelectric materials

***Learning Objectives:***

At the end of this course, students:

- will be able to classify crystals according to their symmetry;
- will be able to find structural information from experimental data;
- will be able to recognize different deviations from the perfect crystal;
- will be able to make a link between the structure and properties of crystalline materials.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | English | English | English |

## M1MET : METALLIC MATERIALS

*Keywords: structure, reactivity, phase diagram, solidification*

| | |
|---|---|
| Teachers | Frédéric Prima |
| Coordinator | frederic.prima@chimieparistech.psl.eu |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 24 h | 4.5 h | 3h | | 75% | | 25% | | |

***Description of the teaching module:***

This course aims to give students a basics in structural metallurgy. It addresses different related aspects

- Microstructures of metal alloys: structural aspects (defects), chemical aspects (diffusion), thermodynamic aspects
- Study of structure/property relations (introduction)
- Solidification of alloys (the genesis of these microstructures)
- Phase diagrams (binary and ternary)
- Phase transformations: kinetic, thermodynamic and crystallographic aspects
- Industrial processes for the manufacture of metallic materials (thermomechanical treatments).

The course is completed by practical work on metallurgy illustrating the relationship between microstructure and mechanical properties (quenching and tensile studies)

***Learning Objectives:***

At the end of this course, students:

- Will master the different concepts of metallurgy.
- Will know how to relate the thermodynamic aspects to the microstructures of metallic materials.
- Will understand the relationship between the microscopic aspects of a material and its macroscopic properties in terms of mechanical behaviour.
- Could develop a synthesis strategy in relation to the expected properties of an alloy.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | 21h course, 3h supervised exercises | English | English |

## M1MECA : INTRODUCTION TO MECHANICS

*Keywords:* deformation; elasticity; rheology; mechanical modelling

| | |
|---|---|
| Teachers | Cristian Ovalle |
| Coordinator | cristian.ovalle@mines-paristech.fr |

| *ECTS* | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 16 h | 8 h | 3h | | 100% | | | | no |

***Description of the teaching module:***

The course begins with the study of the generalities of material properties and the mechanical tests commonly used to characterise their mechanical behaviour. It continues with the study of the construction of material behaviour models and stress state criteria. Then, we focus on linear elastic, thermoelastic and viscoelastic behaviour, followed by the modelling of plastic strain hardening. The last part of the course deals with the main damage and failure models of materials.

Content

- Introduction: Material Properties – Mechanical Testing
- Basic laws - Rheology: types of "deformation" – fundamental basis
- Criteria: criteria not involving hydrostatic pressure - criteria involving hydrostatic pressure
- Elasticity: linear elasticity – linear viscoelasticity
- Plasticity: experimental results – mechanical modelling – elastoplastic behaviour
- Damage and fracture: description – Fracture mechanics

***Learning Objectives:***

- Know how to recognize different mechanical tests,
- Know how to build models of behavior,
- know the mechanical behavior of materials to a given stress.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | English 16h course, 8h supervised exercises | English | English |

## M1COR : ELECTROCHEMISTRY

*Keywords : Oxidation-reduction, Nernst potential, electromotive force, battery, electrolysis, Potential intensity curves, electro-deposition*


Teacher Coordinator: Virginie Lair

Virginie.lair@chimieparistech.psl.eu


| *ECTS* | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 8 h | 4 h | | | | | | | no |

***Description of the teaching module:***

The course aims to redefine the basics of electrochemistry in order to apply it to battery systems. The possibility of electrochemically deposition process for thin films will be presented. The establishment of potential intensity curves will be discussed.

- Reminder on the notions of oxidation-reduction, half-equations redox
- Nernst Potential
- Electromotive force
- Faraday's Law
- Potential intensity curves: reading, origin and application to energy systems
- Electrochemical techniques: application to thin film deposition

***Learning Objectives:***

At the end of this teaching module, students will be able to:

- understand the fundamental aspects of electrochemistry,
- apply and express basic formulas (Faraday's law, Nernst potential,...)
- read and draw curves i = f (E),
- digitize and describe the different electrochemical techniques
- determine the conditions for the deposition of a material

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | 8h course + 4h exercises | English | English |

## M1PROG : PROGRAMMING

*Keywords :* Programming, Python, digital, experimental, visualization

| | |
|---|---|
| Teachers | Basile Marchand |
| Coordinator | basile.marchand@mines-paristech.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 9 h | | 9 h | | | 30 % | | 70% | yes |

***Description of the teaching module:***

The mastery of computer tools and especially programming is now essential in many fields including mechanics. Whether the latter is digital or experimental, mechanics can no longer be done without programming. Indeed, the means of experimentation and especially of acquisition, with the trivialization of the image correlation as well as the magnitude taken by the in-situ tests under tomography, generate volumes of raw data more and more important. It is therefore essential to automate and optimize the post-processing of this mass of experimental data. To do this, programming is essential and the Python language lends itself perfectly to all the necessary operations, from the simple reading of text files to the analysis of images through the filtering of signals. The basics of Python as well as the use of the main scientific modules (Numpy, Scipy, Matplotlib, Scikit) will be exposed during this course.

This Teaching Module is organized in 6 sessions of 3 hours. Most of the sessions take place in two parts: the first devoted to the presentation of concepts and tools and the other to practical work.

The Teachin Module assessment is done in two parts:

- 30% continuous evaluation: participation, involvement in the practical work, ...

- 70% project: realization of a programming project in pairs with a defense.

***Learning Objectives:***

The objective of this course is to provide students with the necessary knowledge elements in Python programming, which will subsequently enable them to:

- Know how to process experimental data from mechanical tests
- Know how to represent complex data in a simple and efficient way
- Be able to perform simple numerical calculations (EDO integration, optimization, ...)
- Know how to find your way around, get informed and document yourself on the Python ecosystem and all the additional modules available

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | 9 h course, 9 h exercises | English | English |

## M1METEXP : EXPERIMENTAL METHODs

*Keywords :* Characterization, image analysis, metrology

| | |
|---|---|
| Teachers | Marie-Hélène Berger, Franck N'Guyen, Hala Rameh |
| Coordinator | marie-helene.berger@mines-paristech.fr |

| ECTS | Course | Exercises | Practical | Tutoring | Written Exam | Continuous Eval. | Practical Exam | Oral Exam | Mixed Eval. |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 24 h | | 6 h | | 100% | | | | no |

***Description of the teaching module:***

The aim of this Teaching Module is to introduce experimental methods conventionally used in the field of materials.

Part of the Teaching Module will be devoted to the introduction of experimental techniques for characterization of materials. After an introductory course, two half-days of visits/demonstrations are organized in two PSL laboratories.

A second part will introduce the concepts associated with image analysis.

An introduction to metrology and data analysis will conclude this Teaching Module.

***Learning Objectives:***

- Know experimental techniques for characterization of materials
- Be able to choose the most relevant technique(s) to obtain the information sought
- Have the basics in image analysis and data analysis

| | | | |
|---|---|---|---|
| *Language* English | Course, Exercises, Practical, Tutoring | *Documents* English | *Literature* English |

## M1BIB : LITERATURE REVIEW: CONDUCTING AND WRITING

| | |
|---|---|
| | *Keywords :* bibliography, state of the art, references… |
| Teachers | Vincent Guipont, Domitille Giaume |
| Coordinator | vincent.guipont@mines-paristech.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 9 h | | | | 50% | | | 50% | no |

***Description of the teaching module:***

This Teaching Module consists of an introduction to the use of digital tools, in particular to carry out a bibliographic study around a defined subject. In order to allow the student to understand the interest of such a work, this bibliographic project is coupled with a period of experimental work in the laboratory in semester S2.

***Learning Objectives:***

The objective for the student is:

- To learn how to search for existing and available data on a topic;
- To extract relevant information from a scientific paper;
- To know how to transcribe correctly and without plagiarizing general ideas emanating from several sources;
- To have an overall perspective and synthesize the information collected

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | 6h introduction to data search | English | English |

| M1PIG : INNOVATION GROUP PROJECT | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Keywords:* creativity, innovation, project management, prototype | | | | | | | | |
| Teachers | Philippe Barboux | | | | | | | | |
| Coordinator | philippe.barboux@chimie-paristech.fr | | | | | | | | |
| ***ECTS*** 3 | *Course* | *Exercises* | *Practical* | *Tutoring* 27h+18h | *Written Exam* 50% | *Continuous Eval.* | *Practical Exam* | *Oral Exam* 50% | *Mixed Eval.* yes |

***Description of the teaching module:***

The goal of these innovation group projects is to continue learning project management and teamwork through the development of a technological innovation project. A technological project is a study designed to develop an idea initiated by a client. This must proceed from an innovation approach aimed at creating a new product, a new service, a new good, adding that we can include a new process, a new recipe closer to chemistry.

Project progress:
The projects are carried out in five phases:

1. Search for topics and organization of the team and project
2. Study of the state of the art and analysis of resources (patents, publications, internet, customer visit
3. Elaboration of the project and proposal phase to the steering committee. Critical discussion and defense of the project. Possible ordering of the material
4. Technical realization, development
5. Restitution (video 10 minutes or written report 15 pages then oral defense of the project.

***Learning Objectives:***

The goal of learning is to learn how to develop interdisciplinary skills

- in the field of project management (schedule, schedule, programming)
- in the scientific and technical field (state-of-the-art analysis, bibliography, initiative, design and development of an innovative product)

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| Englsih | 27h + 18h tutored project | En/Fr | En |

| **M1ANG : LANGUAGES** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Keywords:* | | | | | | | | |
| Teachers | | | | | | | | | |
| Coordinator | Linda Koiran / linda.koiran@mines-paristech.fr | | | | | | | | |
| ***ECTS*** 2 + 2 | *Course* 20h+20h | *Exercises* | *Practical* | *Tutoring* | *Written Exam* 50% | *Continuous Eval.* | *Practical Exam* | *Oral Exam* 50% | *Mixed Eval.* non |

***Description of the teaching module:***

This Teaching Module allows students to learn a foreign language and thus open their horizons to be able to communicate effectively in the scientific world and within a company in France.

***Learning Objectives:***

The objective of this Teaching Module is that each student has a minimum level in French and English.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| En/Fr | 2x20h course | En/Fr | En/Fr |

## M1MOD : MOLECULAR MODELLING

| | |
|---|---|
| | *Keywords:* molecular modeling |
| Teachers | Frédéric Labat |
| Coordinator | frederic.labat@chimie-paristeh.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 6h | | 9h | 4.5h | 50% | | | 50% | no |

***Description of the teaching module:***

This Teaching Module aims to train the student in quantum and classical modeling of complex systems (molecules, solids, biomolecules) of industrial interest. Methods for describing spectroscopic properties (IR, Raman, UV-Vis, NMR and RPE) and chemical reactivity are particularly targeted. Particular interest is given to simulation methods currently used in the industrial and application field, and their use is illustrated by courses and seminars given by two external speakers from public or private institutions presenting their activity, in order to strengthen the link between modeling and the business world. The training is based on alternating course and practical work sessions, which allow students to put into practice the methods described in class using software of academic and industrial interest.

***Learning Objectives:***

The student must be able to:

- to choose the most suitable method according to the properties and the system
- to interpret the results obtained and their limits
- interact with modeling experts

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| En | | En/Fr | En |

## M1ELAB : INORGANIC MATERIALS ELABORATION

*Keywords:* inorganic synthesis, ceramic, monocristalline synthesis ; thin films

| | |
|---|---|
| Teachers | Gérard Aka ; Domitille Giaume ; Odile Majerus |
| Coordinator | domitille.giaume@chimieparistech.psl.eu |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 22h | 2h | | | 100% | | | | no |

***Description of the teaching module:***

This course presents the fundamentals of materials elaboration.
A first part presents the basics of monocrystalline synthesis, starting from reflexion based on phase diagrams, nucleation-growth concepts and illustrations with various hot-temperature monocrystalline routes. Such routes are predominant in the optic and photovoltaic domains. A second part deals with the physical and chemical principles underlying the solid-state densification and sintering of powders to obtain technical ceramics. Technical ceramics are a wide family of high-value materials for structural or functional applications (magnetic, optic, dielectric…). On the other hand, glass and glass-ceramics are materials prepared from the liquid state. Their elaboration is briefly presented at the end of this part. . The third part concerns the synthesis of such small inorganic materials by low temperature routes. Basics of aqueous precipitation, sol-gel condensation, high-boiling solvent synthesis are thoroughly described. The last part presents the different opportunities and methods for a chemist concerning the specific elaboration of thin or thick films.

***Learning Objectives:***

At the end of this course, the students:

1. are aware of the various synthesis routes to elaborate inorganic materials;
2. Can evaluate the pros and cons of a specific synthesis route;
3. can chose the most adapted synthesis route for their study;
4. understand the mechanisms involved in the various synthesis routes;
5. propose consistent modification of the synthesis.

| *Language* | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |
|---|---|---|---|
| English | | En/Fr | En/Fr |

## M1PES : ELECTRON PROPERTIES OF SOLIDS: FROM THE MACRO TO THE NANO SCALE

*Keywords:* electron band structure, semiconductors, devices, nanosciences

| | |
|---|---|
| Teachers | Laurent Binet, Didier Gourier, Pascal Loiseau, Frédéric Wiame |
| Coordinator | Laurent.binet@chimieparistech.psl.eu |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 19.5 h | 4,5h | | | 100% | 0% | 0% | | |

***Description of the teaching module:***

This Teaching Module is an introduction to the electron properties of solids and to their applications in semiconductor-based devices.

The first part introduces models (free electron gas, tight-binding) and general concepts about electron band structures in crystalline solids. It is shown how these concepts explain the general electrical and optical properties of materials.

The second part focuses on semiconductors and the p-n junction. Devices based on this junction are described, including laser or light emitting diode and solar cells.

The third part is an introduction to nano-sciences and nano-devices and deals with new effects arising from the down-sizing of conducting materials, such as Coulomb blockade, electronic interferences effects and giant magneto-resistance.

***Learning Objectives:***

1. understand the concepts and models describing the electronic mobility in a crystalline solid ;
2. understand the electronic band structure of a solid and link it with electric or optical properties ;
3. understand the principle of semi-conductor-based devices
4. - identify the major materials parameters at the origin of their performances

| *Language* English | Course, Exercises, Practical, Tutoring | *Documents* En/Fr | *Literature* En/Fr |
|---|---|---|---|

## M1INORG : Inorganic chemistry : from molecules to materials

*Keywords:*

| | |
|---|---|
| Teachers | Philippe Barboux, Domitille Giaume |
| Coordinator | philippe.barboux@chimie-paristeh.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 10.5h | 7.5h | | | 100% | | | | no |

***Description of the teaching module:***

The objective of this course is to give the rules of construction of all inorganic and mineral systems but also to show how much this inorganic chemistry is alive and has many applications in current problems (energy, environment, information storage, nanotechnologies...). An introduction to the industrial mineral chemistry industry completes the course (cements, glasses, aquatic chemistry, batteries). The theoretical part focuses on transition metal and lanthanide complexes and describes in particular their optical and magnetic properties.

***Learning Objectives:***

At the end of the course:

- The student knows the periodic table and the trends of the different elements (ionization, complexation, orbital levels).
- He can describe a mineral system and choose between two simple approaches to describe inorganic complexes according to two ion binding or covalent binding models.
- He can explain the stability and reactivity of inorganic molecules based mainly on transition elements or elements of the p-block.

| | | | |
|---|---|---|---|
| *Language* English | Course, Exercises, Practical, Tutoring | *Documents* | *Literature* |

## M1SMM : SURFACE PROPERTIES AND ENDURANCE OF MATERIALS

*Keywords:* surface characterization, nanostructuring, reactivity

| | |
|---|---|
| Teachers | *Philippe Vermaut, Frédéric Wiame, Anouck Galtayries* |
| Coordinator | frederic.wiame@chimieparistech.psl.eu |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 21h | 3h | | | 100% | | | | no |

***Description of the teaching module:***

What is a surface? What are the specificities of surfaces compared to bulk? Why and how to study these surfaces? In this course we will try to answer these questions. The concepts of surface energy and stress will be introduced and their effects on the structure and properties of the surface will be studied. The initial stages of reactivity will be characterized in the framework of the adsorption theory.
The course will be illustrated by practical examples: growth of an oxide on an alloy, evolution of a metal interface in the presence of sulfur. These examples will highlight the different information that can be obtained using surface characterization techniques. Nanostructured surface fabrication methods will also be presented and the effects of nanostructuring on surface properties will be discussed.
After having seen the relationship microstructure-mechanical properties of metals, we propose here to go further by looking at the mechanisms that lead to the breaking of materials when exposed to mechanical loading or aging in a defined environment. This will allow us to address the issue related to the durability of metallic materials in conditions of use.

***Learning Objectives:***

At the end of the course the student will be able:

- to identify and explain the main technological issues of the study of surfaces,
- to describe the fundamental differences between the properties of a surface and those of the bulk material,
- to determine the structure, characteristics and basic properties of a surface of given orientation,
- to describe the different adsorption mechanisms and give their main characteristics,
- to justify the usefulness of ultra-high vacuum and electronic spectroscopies for surface analysis and to identify the most appropriate techniques to answer a given problem,
- to highlight, by means of examples, the importance of the structure and the surface composition on the mechanisms and the kinetics of reactivity.

| | | | |
|---|---|---|---|
| *Language* English | Course, Exercises, Practical, Tutoring | *Documents* En/Fr | *Literature* En/Fr |

| **M1FLOWCHEM: Advanced fluid mechanics** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Keywords:* microfluidics, Reynolds number, heat transport, hydrodynamic instability | | | | | | | | |
| Teachers | Nicolas Brémond, Marc Fermigier, Laurent Duchemin | | | | | | | | |
| Coordinator | | | | | | | | | |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 30 h | | | | 100% | | | | no |

***Description of the teaching module:***

A first part of the course (8h) deals with Microfluidics (AFM-MIC) and focuses on the mechanics of low Reynolds number fluids in confined systems where interfaces play a preponderant role. The monophasic, bi-phasic, dispersion properties, colloidal or not, are presented. The possibility of modifying these flows in control of pressure, temperature or electromagnetic fields is also discussed.

A second part (12 h) deals with Physics of Transport (AFM-PT) of mass and heat. It will answer a wide variety of questions such as: why does my coffee cool much faster than the sugar diffuses into the cup? How long can I stay on top of Everest without gloves? How to design a microfluidic chip to effectively capture biomolecules? How many showers can I take per day with a 10 square meter solar water heater? What do cetaceans and heat exchangers have in common? Why is mixing in turbulent flows so effective?

The last part (10h) is a course of Hydrodynamic Instabilities (AFM-HI). After the introduction of the general concepts of stability study, we will focus on the instabilities antcipient in a fluid initially at rest: in particular, we will treat the so-called Rayleigh-Taylor instabilities related to gravity and that of Rayleigh-Bénard observed in a fluid heated from below. Next, we will describe the instabilities of parallel flows, from which large structures can emerge (Kelvin-Helmholtz). Finally, we will focus briefly and phenomenologically on isotropic homogeneous turbulence (Kolmogorov theory).

***Learning Objectives:***

- Identify the different microfabrication techniques and select the most relevant
- Solving low Reynolds number problems and electrohydrodynamic problems
- Identify heat and mass exchange mechanisms
- Compare different modes of transport using dimensionless numbers
- Model a diffusion, radiative, or convection transport problem
- Identify the mechanisms of instability of a fluid at rest or flow
- Formulate a linear stability problem with or without a free surface, and establish the dispersion relationship

| *Language* English | Course, Exercises, Practical, Tutoring | *Documents* En | *Literature* En/Fr |
|---|---|---|---|

## M1MECASOL : Mechanics of solids and materials

| | |
|---|---|
| | *Keywords:* |
| Teachers | Matteo Ciccotti, Zorana Zeravzic, José Bico, Pascal Kurowski |
| Coordinator | matteo.ciccoltti@espci.fr |

| ***ECTS*** | *Course* | *Exercises* | *Practical* | *Tutoring* | *Written Exam* | *Continuous Eval.* | *Practical Exam* | *Oral Exam* | *Mixed Eval.* |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 18 h | 5 h | | 4h | 100% | | | | no |

***Description of the teaching module:***

The Mechanics of Solids and Materials course is oriented towards the aspect mechanical properties of materials. It develops the main types of behavior by identifying their physical origin. The viscoelastic, plastic and fracture characteristics of the major classes of materials are addressed in parallel with the study of the corresponding laws of behaviour. A study of simple stresses identifies the guiding ideas guiding the choice of a material according to the intended application (structure and loading). A light formalism methodology will be used to approach the physical modeling of more complex situations encountered in common life or in modern applications.

Contenu :

1. General information on the strength of materials
2. Classes of materials and families of behaviour
3. Basics about Continuous mechanics (strain and stress tensor, fundamental equation of equilibrium)
4. Reminders of 3D linear elasticity (Young's and Lamé's law, elastic modules, elastic energy)
5. In-depth studies on linear elastic behaviour (energy theorems, stability analysis, solution of problems in scale law)
6. Waves and vibrations
7. Viscoelastic behavior: rheological models, time and frequency representation, time-temperature equivalence
8. Plastic behavior: rheological models, plasticity criteria
9. Perfect plasticity, work hardening, viscoplasticity
10. The paradox of theoretical resistance to rupture
11. Linear Elastic Fracture Mechanics (LEFM)
12. Local criterion: stress intensity factor (Irwin)
13. Energy criterion: Griffith length and fracture work
14. Fragility and ductility: dissipation mechanisms, length and time scales
15. Slow fracture and rapid fracture
16. Heterogeneous materials: inclusions, composites
17. Contact, adhesion and friction

***Learning Objectives:***

| | | | |
|---|---|---|---|
| *Language*<br>English | Course, Exercises, Practical, Tutoring | *Documents*<br>En/Fr | *Literature*<br>En/Fr |

# PRACTICAL INFORMATION

## Registration institution

Chimie ParisTech
11 rue Pierre et Marie Curie
75005 PARIS
www.chimie-paristech.fr

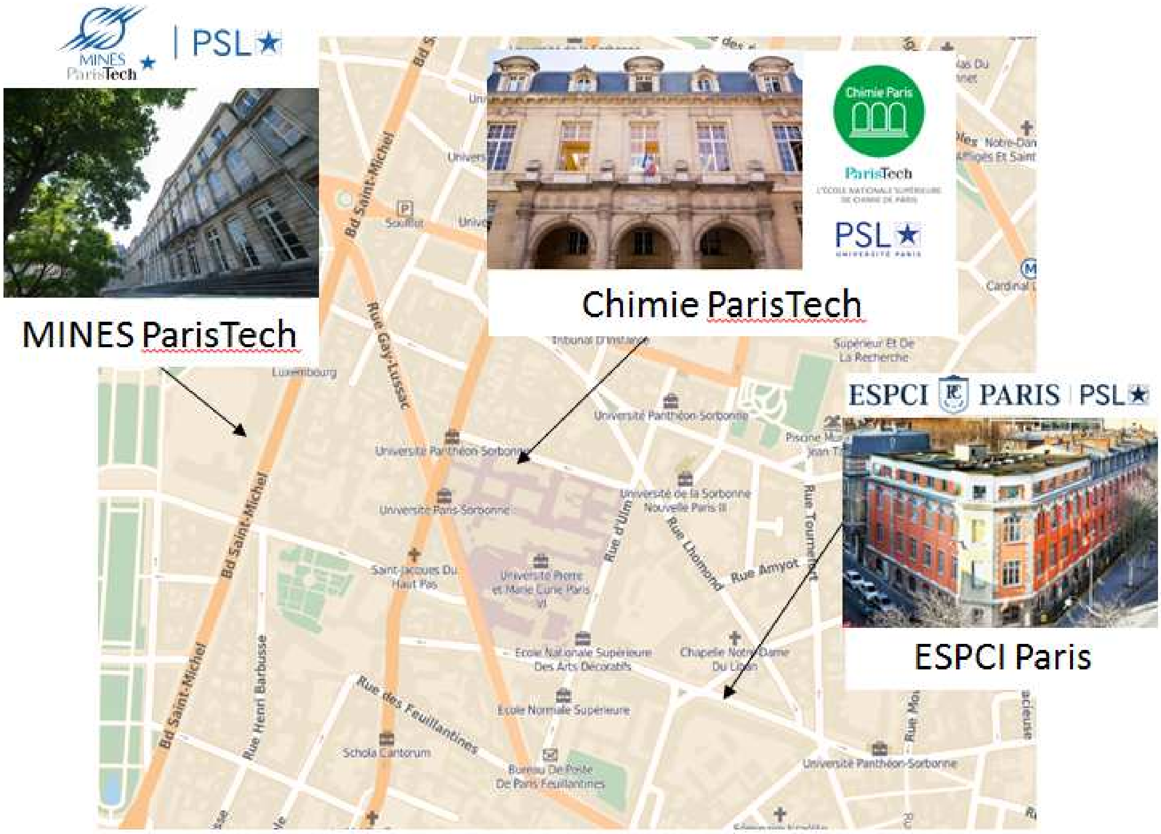
## Places for Courses

La très grande majorité des enseignements a lieu dans les trois établissements partenaires du master : Chimie ParisTech, MINES ParisTech, ESPCI Paris.

| | | |
|---|---|---|
| Chimie ParisTech<br>11 rue Pierre et Marie Curie<br>75005 PARIS<br>www.chimie-paristech.fr | MINES ParisTech<br>60 boulevard Saint-Michel<br>75006 Paris<br>www.mines-paristech.fr | ESPCI Paris<br>10 rue Vauquelin<br>75005 PARIS<br>www.espci.fr |

Part of the first year of the M1 is shared with Teaching Modules of the engineering cycles of the partner institutions. Some courses are also transversal to other PSL Masters (in particular the PSL Energy Master), and will be mutualized for a greater richness of the profiles.

The institutions where the courses are held are all located in the heart of the Paris Latin Quarter.



## Contacts

***Materials Science and Engineering:***

Vincent Guipont & Domitille Giaume, co-directors (contact.master-sgm@psl.eu)

https://www.psl.eu/formation/master-sciences-et-genie-des-materiaux

***Welcome Desk PSL :*** welcomedesk@psl.eu / +33 (0)1 75 00 02 91

The Welcome Desk supports newcomer international students in their administrative procedures.

Throughout the year, the PSL Welcome Desk team, composed of bilingual students, also organizes many activities: language tandems, culinary workshops, group jogging, visits to Paris, student evenings, etc.

Every week, the Welcome Desk newsletter will inform you of available activities.