Master 2 Microfluidique
Syllabus 2024 - 2025

Preliminary version subject to changes

Website : http://microfluidics-master.wordpress.com

1. General Organization

1.1. Presentation

The Microfluidics degree (Master 2), associated to the Institut Pierre-Gilles de Gennes, is an interdisciplinary degree, oriented towards innovation and industrial applications. In a few words the shortest way to take part to the start-up ecosystem in the microfluidics domain.
The degree is part of

- the « Physics of Complex System » Master's degree (Sorbonne Université, Université Paris Cité et Université Paris Saclay) for physicist students,
- the « Materials Science and Engineering » (Université PSL) Master's degree for chemists and biologists.

The Microfluidics degree is committed to deliver a high-level technological training to the students, that will be achieved through a set of lab classes taking place on the technological platform of IPGG, the conduction of a Master's project and ultimately culminating in a Master's thesis.
The overall content of the Microfluidics degree is equal to 60 ECTS, from beginning of september to the end or june or july.

1.2. Schedule, updated informations

The up-to-date schedule can be viewed here (pwd : ipggipgg):
https://microfluidics-master.fr/schedule/

1.3. Numerical tools and resources

Discord Server

For internal, everyday communication, we use a Discord server. You will receive the invitation at the beginning of the year.

Google Classroom

All teaching resources, and some assignments, are stored on a Google Classroom server. You will receive the courses to enroll at the beginning of the year.

2. Semester 1 - List of courses

2.1. Micro-hydrodynamics

Course code : HYDRO

Course Instructor(s): N. Bremond (LCMD, ESPCI. nicolas.bremond@espci.fr), J. McGraw (LCMD, ESPCI. joshua.mcgraw@espci.fr), S. Aimé (C3M, ESPCI. stefano.aime@espci.fr)

Hydrodynamics N. Bremond (12h)

- Navier-Stokes equation
- Low-Reynolds number hydrodynamics
- Modes of transport (diffusion, convection, electro-osmosis)
- Hydrodynamics phenomena at intermediate Reynolds numbers in microsystems (ex. Dean flows)

PIV and PTV S. Aimé (4h)

- PIV and PTV

Interfacial hydrodynamics and formulation N. Bremond (6h)

- Microfluidics and spray: hydrodynamics and applications
- Microfluidics and emulsion: hydrodynamics, physicochemistry and applications

Stokes flows in the lubrication approximation: Fundamentals and application to micro and nanofluidics J. McGraw (9h)

- How does spin coating work ?
- Surface-tension-driven, thin-film flows
- Reynolds' slipper bearing: lift and drag on a sliding plane
- Reynolds' sphere: nanofluidics
- Elastohydrodynamics in microfluidics

Useful resources :

- Bruus, H. (2007). Theoretical microfluidics (Vol. 18). Oxford university press
- Guyon, E., Hulin, J. P., Petit, L. and Mitescu, C. D. (2001). Physical hydrodynamics. Oxford university press
- Cabane, B., & Hénon, S. (2015). Liquides. Solutions, dispersions, émulsions, gels: Solutions, dispersions, émulsions, gels. Belin Éducation.

2.2. Microfabrication

Course code : MICROFAB

Course Instructor(s): J. Fattaccioli (Dpt of Chemistry, ENS), M. Morel (Dpt of Chemistry, ENS)

Lectures : 19h, Lab classes : 12h

Content :

- Basics of silicon microfabrication : lithography, etching, thin-film deposition, mask alignments, etc.
- PDMS and NOA microfabrication
- Surface functionalization

In addition to the lectures, lab classes are organized :

- CAD Design and lithography
- Single-phase (diffusion, gradients) and multiphase flows (droplet generation)

2.3. Introduction to biology

Course code : INTROBIO
Course Instructor(s): L. Tricoire, W. Keil

Lectures : 12h

Content :

- DNA structure and genetic basis of heredity
- Gene expression (RNA structure and transcription)
- Protein translation and structure
- Conventional methods for DNA, RNA and protein analysis.
- Microfluidic methods for genome, transcriptome and proteome studies
- Gene editing methods.
- Overview of the most common model organisms
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2.4. From soft to active matter

Course code : ACTIVE
Course Instructor(s): P. Silberzan (I. Curie), M. Thery (ESPCI)

Content :

- Cell monolayers.
- Microswimmers and chemotactism
- Collective behavior of bacteria and cells
- Cytoskeleton

2.5. Single molecule approaches for dynamics and super-resolution imaging in biological systems

Course code : SINGLEMOL
Course Instructor(s): B. Hajj

Content :

- Basic concepts in photonic microscopy (brightfield, fluorescence)
- Fluorescence markers
- Consideration for single molecule detection
- Single molecule imaging tracking
- Super-resolution microscopy

2.6. Capillary and wetting phenomena

Course code : CAPILLARITY
Course Instructor(s): D. Quéré, H. de Maleprade
Lectures : 14h, Tutorials : 14h

Content : In this course, we will introduce the key concepts of soft matter, seen from the perspective of its interfaces.
We will place particular emphasis on the role of soft material interfaces (they are, for example, the ones that "harden" shaving foam), starting from the definition of an energy of an interface and exploring some of its countless consequences. The course will thus introduce the elementary concepts of soft matter and its interfaces - adsorption, wetting, entropic forces, osmosis,...-, as well as the toolbox that allows us to describe it, coupling physics of continuous environments (capillarity, wetting, hydrodynamics, elasticity, electrodynamics of interfaces,...) and statistical physics (phase transitions, fluctuations, Langevin equation,...). The objective is to give a panorama of soft matter from macroscopic properties to its microscopic foundations.
This teaching will be based on a number of key experiences, and we will often use scaling laws approach to analyze them.

Ressources :

- **Capillarity and Wetting Phenomena : Drops, Bubbles, Pearls, Waves**. P.-G. De Gennes , F. Brochard-Wyart , and D. Quéré (translated from French by Axel Reisinger) Springer-Verlag, New York, 2004. French version publisehd by Dunod. https://physicstoday.scitation.org/doi/10.1063/1.1878340

2.7. Soft Matter

Course code : SOFTMATTER
Course Instructor(s): Corentin Trégouët, T. Derkenne

- Basis of thermodynamics and stastical physics
- Molecular diffusion, Knudsen diffusion, Henry law, boundary layers
- Solid / liquid interfaces : surface forces, van der waals, hydrophobic forces, debye length
- polymer physics : random walk, polymer brushes, solvent affinity, protein shape
- polymer physics : polymer elasticity, polymer brushes and microcapsules
- mechanical waves: capillary waves, acoustic streaming, acoustofluidics
- phase separation: binodal/spinodal curves, LCST/UCST

2.8. Blue Energy

Course code : BLUENERGY
Course instructor : Corentin Trégouët, T. Derkenne

Content :

- What is this new source of renewable energy? How does it relate to osmosis and the mixing entropy?
- How to harvest it? Focus on 2 technologies: capacitive mixing and reverse electro-dialysis.
- What are the physical and chemical mechanisms of charge separation, transport and energy conversion: Debye length, Gouy-Chapman theory, Buttler-Vollmer equation ?
- What are the current scientific challenges and emerging technologies?

2.9. Rheology

Course code : RHEOLOGY
Course Instructor(s): A. Lindner
Lectures : 21h – Lab class : 12h

Content :

- Classic and microfluidic rheometry for simple and complex fluids

- Non-Newtonian properties (rheofluidification, normal stresses, viscoelasticity, flow threshold)
- Typical complex fluids: polymer solutions, biological fluids, suspensions, active fluids, gels

2.10. Analytical chemistry

Course code : ANACHEM
Course Instructor(s): F. d'Orlye (ChimieParistech), K. Perez-Toralla (CEA), J. Baudry (ESPCI)

Content :

- Miniaturization for analytical chemistry
- Physical aspects of immunoassays
- Immunoassays : from basic to advanced setups

2.11. Flow chemistry

Course code : FLOWCHEM
Course Instructor(s): S. Ognier (ChimieParisTech)

Content :

- Mass and thermal transfers at the milli-fluidic scale
- Milli-flluidic reactors design
- Industrial examples of synthesis made by flow chemistry

2.12. Organ on chip

Course code : OOC
Course Instructor(s): S. Descroix, C. Aimé, L. Muller, S. Coscoy

Content :

- Collagen and extracellular matrix properties (4h)
- Why using OoC as organ models for pharmacology or basic science ? Some examples : Intestine, heart and lung-on-chip (6h)
- Plant and fungi on chip (2h)

3. Semester 1 - Short-term Research Project (S1)

The short-term research project objectives are twofold :

- Conducting a bibliographical research on a specific topic defined in agreement with the hosting laboratory
- Participating to the hosting lab research by working on a numerical aspect of an ongoing project in the lab (modelling, images analysis, data analysis, etc.)

More information on the projects are communicated each September.
The Short-term Research Project has to be done in an academic laboratory member of the Institut Pierre-Gilles de Gennes or a team of one of the instructors of the M2 Microfluidics. For the list of the laboratories associated to IPGG : http://www.institut-pgg.com
Start-ups or research centers in private companies are not allowed. A project can be done in an academic laboratory in collaboration with a start-up or a private company.
Projects start at the end of September and have to be conducted during the time slots empty of any lectures, lab class or any mandatory event.

Important : You cannot start doing experiments without having a proper "convention de stage" signed by you, the lab and the university. Until receiving the signatures, you can start by doing a bibliographical work.

Students are expected to produce a written report on these two aspects of the research project, and present their work in front of a jury.

4. PSL Week (specific to PSL SGM / Microfluidique students)

For students enrolled in the M2 Sciences et Genie des Matériaux @PSL : http://www.pslweek.fr/.
Students enrolled in the Physics of Complex Systems M2 are expected to work on their Short-Term Research project.

5. Semester 2 : Research Internship

The Long Research Internship can be done in an academic laboratory, a start-up or research centers in private companies; in France or abroad.
The content of the internship has to be validated by the M2 coordinator (J. Fattaccioli). A project can be of course done in an academic laboratory in collaboration with a start-up or a private company.

Projects start at the beginning of February and should last **at least 5 months (full time)**. They should however be **shorter than 6 months** due to national regulations (= it is the law).
Depending on the university where the students are administratively enrolled, the procedure related to the “convention de stage” (internship agreement) can vary.
Please ask for details **well in advance** (December…) to be sure that no delay will forbid you to start your internship.

6. Elective courses (no ECTS granted)

6.1. ABC-AC — Advanced Biology Course on Artificial Cell

This course explores the foundational principles of life through the construction and study of artificial cells—minimal systems assembled from lipids, proteins, and nucleic acids that emulate essential biological functions. By focusing on bottom-up design rather than the modification of existing cells, students gain insights into the structural, informational, and interactive components of living systems. The pedagogical approach emphasizes critical thinking, data analysis, and communication skills, with a strong emphasis on student participation. Each 2-hour session includes expert-led presentations on key studies and current challenges (90 minutes), followed by student presentations of selected research articles (30 minutes), fostering collaborative learning and active engagement with cutting-edge scientific literature.

More details : https://www.edu.bio.ens.psl.eu/spip.php?article289

6.2. PSL i-Teams : Entrepreneurship and Innovation

Since 2017, PSL organizes each year the PSL-iTeams program. It is a training path intended for master’s students, doctoral students and post-doctoral students interested in innovation or entrepreneurship, from all disciplines and all institutions (engineering schools, art schools or humanities and social sciences schools, etc.).
This program aims to develop their entrepreneurial, innovation and leadership skills, while contributing to the development of inventions, results and knowledge from PSL research teams.

Students interested to apply for the program and join should contact the M2 Microfluidics coordinators at the beginning of september to learn about the updated procedure.

More information : https://psl.eu/en/node/2121