Master 2 Microfluidique

Syllabus 2023 - 2024

Preliminary version subject to changes

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

Contents

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 Important dates

- Thursday, 9th of September, 2022: Start
- 21/11/2022 - 25/11/2022 : PSL Week
- 19/12/2022 - 01/01/2023 : Christmas vacations
- January 2023 : Exams (Details will be given later)
- Monday, 06/02/2023 : Earliest date to start of the Long-term research internship

3 Semester 1

3.1 UE Microfluidics and Microfabrication

Objectives : bla

3.1.1 Micro-hydrodynamics (CM 30h)

Course code : HYDRO
Course Instructor(s): MC Jullien (IPR, Université de Rennes 1. marie-caroline.jullien @espci.fr), N. Brémond (LCMD, ESPCI. nicolas.bremond @espci.fr), J. McGraw (LCMD, ESPCI. nicolas.bremond @espci.fr)

Hydrodynamics M.C. Jullien (15h)

- 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)

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

Assessment : The exam will consist in a written report on a research article.
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.

3.1.2 Microfabrication

Course code : MICROFAB
Course Instructor(s): J. Fattaccioli (Dpt of Chemistry, ENS), M. Morel (Dpt of Chemistry, ENS) , B. Le Pioufle (ENS Paris-Saclay, A. Colin (ESPCI)
Lectures : 19h, Lab classes : 15h

- Basics of silicon microfabrication : lithography, etching, thin-film deposition, mask alignments, etc.
- PDMS and NOA microfabrication
- Bio-MEMS : interfacing silicon with biology
- Flexible electronics : How to manufacture flexible, stretchable, self-healing electronic components using simple microfabrication techniques? How to power embedded sensors using the energy of mechanical vibrations?
- Nanofabrication : E-beam lithography, nano-imprint

In addition to the lectures, labclasses are organized (16h) :

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

Assessment : The exam will consist in a written report on a research article.
Courses : written exam - Lab class : lab class report

3.1.3 Chemistry of functional surfaces

Course code : TRAISU
Course Instructor(s): M. Tatoulian, J. Fattaccioli
Lectures(s) : 6h

- Functional surfaces : hydrophobicity and hydrophilicity, chemical functionalization
- Plasma and CVD-based methods for surface modification (PDMS, PS, glass, etc)
- Wet methods for surface functionalization

3.2 UE Biology

3.2.1 Introduction to biology

Course code : INTROBIO
Course Instructor(s): L. Tricoire
Lectures : 12h

- 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.

3.2.2 A biophysicist view on cells and bacteria

Course code : BIOPHYSICS
Course Instructor(s): P. Silberzan
Lecture(s) : 6h

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

3.2.3 Introduction to cell migration and immunology

Course code : MIGRATION Course Instructor(s): M. Piel, P. Vargas
Lectures : 6h

- Introduction to the immune system and its cellular and systemic players
- Use of microfabricated systems to address questions related to cell migration in confined spaces

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

Course code : SINGLEMOL
Course Instructor(s): B. Hajj
Lectures : 9h

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

3.2.5 Model organisms in biology

Course code : MODELORGA
Course Instructor(s): W. Keil
Lectures : 3h

- Overview of the most common model organism, why we use them, and why people use a specific one as compared to the others.

3.3 UE Phenomena at the meso-scale

3.3.1 Capillary and wetting phenomena

Course code : CAPILLARITY
Course Instructor(s): D. Quéré, H. de Maleprade
Lectures : 28h

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

3.3.2 Soft Matter

Course code : SOFTMATTER
Course Instructor(s): F. Restagno

3.3.3 Blue Energy

Course code : BLUENERGY
Course instructor : Corentin Trégouët
Lectures : 9h, Lab class : 4h

- 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?

3.3.4 Rheology

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

- 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

3.4 UE Lab on a Chip

3.4.1 Analytical chemistry

Course code : ANACHEM
Course Instructor(s): F. d'Orlye, S. Descroix, J. Baudry

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

3.4.2 Flow chemistry

Course code : FLOWCHEM
Course Instructor(s): S. Ognier
Lecture(s) : 9h, Labclass : 3h

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

3.4.3 Organ on chip

Course code : OOC
Course Instructor(s): S. Descroix, C. Villard, C. Aimé
Lecture(s) : 22h

- 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)

3.5 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.

Important rules

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.

Assessment :

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.

3.6 UE Semaine PSL

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.

4 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.

Assessment

5 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.

The workshop is organized weekly, on tuesday from 6 to 8pm (2022/2023).

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

Assessment

Currently, no ECTS is granted to students taking part to the PSL iTeams program.

6 Grades and Coefficients

6.1 General Rules

- A grade greater than 8/20 is necessary to validate a specific course.
- Credits of a given UE cannot be granted if one of its courses is not validated, according to the above rule.
- For each course that is not validated, students have to retake the exam ASAP, according to the expectations of the professor (oral, written, report, etc.)

6.2 PSL Students

6.3 PCS Students

Semester 1

UE (PCS)	CODE (PCS)	PCS Course Name	ECTS	M2 Microfluidics Course Name
UE01	PFICE010	Micro-fluidique	3	HYDRO
UE02	PFICE020	Techniques de micro-fabrication	3	MICROFAB
UE03	PFICE040	Laboratoire sur puce	6	ANALCHEM + OOC
UE04	PFICE030	Introduction à la biologie	3	INTROBIO + BIOPHYSICS + SINGLEMOL
UE05	PFICE050	Tutorat bibliographique	3	S1 INTERNSHIP
UE06	PFICE060	Ecoulements à surface libre	3	CAPILLARITY
UE07	PFICE070	Génie chimique	3	FLOWCHEM + BLUE ENERGY
UE08	PFICE080	Rhéologie des fluides complexes	3	RHEOLOGY
UE09	PFICE090	Interfaces et dispersions	3	SOFTMATTER

Semester 2

	36QU01MI	Stage microfluidique	30	S2 INTERNSHIP

7 Administrative contacts

If you have any question related to administrative issues (enrollment, internship contracts, etc), please send an email to the following people, with J. Fattaccioli's email address in cc (m2microfluidique@gmail.com):

PCS - Sorbonne Université

Secretary : Corinne SALLANDRE : corinne.sallandre@sorbonne-universite.fr

PCS - Université Paris Saclay

Secretary :

PCS - Université Paris Cité

Secretary : Souad Namane : souad.namane@univ-paris-diderot.fr

SGM – Paris Sciences Lettres

Secretary : Kristell Guillou : kristell.guillou@chimiparistech.psl.eu

Written by J. Fattaccioli (jacques.fattaccioli @ens.psl.eu) on behalf of the teaching team, with their help.
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