2EL2020 – Physics of divided matter

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Department: DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS
Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Engineering Sciences
Advanced level : Yes

Description

"God made solids, but surfaces were the work of the devil" (Wolfgang Pauli)
The behavior of dispersed media such as bubbles, drops, liquid films or colloids is strongly influenced by capillary and surface forces. Correlatively, body forces such as gravity play a secondary role. The present course focuses on dispersed systems with characteristic size ranging from 1 mm down to 10 nm.
These systems can be found everywhere around us. Applications concern biology (super-hydrophobic leaves, surfactant film in lungs, cavitation bubble made by a pistol shrimp), environmental science (dynamics of raindrops and their role in the biosphere, sediment siltation in estuaries), technology (fabrication of cosmetic and pharmaceutical emulsions, food industry, fire-fighting or insulating foams, surface treatments, lab-on-a-chip) and daily life (tears of wine, rising humidity and deterioration of houses and historical stone monuments). Numerous industrial innovations are based on the implementation and control of these systems.
The present course introduces the basic concepts of the physics of surfaces and addresses various interfacial phenomena encountered in dispersed systems: capillarity and wetting, colloidal interactions and Brownian motion, interface dynamics and associated instabilities. The role of interfacial energy in phase transformations (nucleation step) will be also discussed.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Transport phenomena (recommended)

Syllabus

The course is divided into three parts: 12 hours of lectures and related tutorials, 12 hours devoted to case studies, 11 hours dedicated to the realization of a miniproject.

Basic concepts (4 x (1.5h lecture + 1.5h tutorials))

1) Notion of surface tension
Physical origin
The thermodynamic and mechanical points of view
Capillarity: Laplace's law
Interfaces and boundary conditions of the Navier-Stokes equations
Area minimisation and minimum surfaces
Tutorial #1: Liquid menisci, capillary forces, wet hair and insects on water

2) Wetting
Ideal solid surfaces: Young-Dupré's law
Contact angle hysteresis
Influence of surface roughness
Influence of chemical heterogeneities
Towards superhydrophobic surfaces
Contact line dynamics
Tutorial #2: Modeling equilibrium contact angles on textured surfaces

3) Surfactants: equilibrium and dynamics
Amphiphilic molecules
Surface concentration and Gibbs adsorption equation
Micelles and critical micellar concentration
Dynamic surface tension and dynamics of surfactants
Interfacial rheology
Tutorial #3: Formation and drainage of a soap film

4) Colloidal scale
Colloids and colloidal systems
Brownian movement and Brownian limit
Interaction forces between surfaces: van der Waals force, osmotic pressure effects
DLVO Theory - Why do estuaries silt up?
Thin liquid films and disjunction pressure
Tutorial #4: Evaporation in a microchannel

Case studies (4 x 3h)

Each case study offers the opportunity to examine physical phenomena of industrial or practical interest, to apply the concepts introduced in the lectures and to become familiar with state of the art modelling methods and mathematical tools. The case studies are carried out by groups of 3 to 4 students and supervised by a teacher. The duration of 3 hours per study allows each group to get to grips with the subject and to work on its own, with the methodological support of its supervisor. At the end of the 3

hours, each group reports its work in a note (handwritten or by word processing, as desired).

5) Capillary rise and imbibition
Applications: from raw sap rising in trees to the manufacture of composite materials
Equilibrium height in a vertical tube
Dynamics of capillary rise: inertial and viscous regimes
Capillary rise in a corner

6) Drainage and deposition of liquid films on a vertical flat plate
From anti-corrosion coatings on steel sheets to anti-reflective coatings on eyeglass lenses
Drainage of a liquid film
Dip coating
Scaling
Landau-Levich-Derjaguin theory: dynamic meniscus and asymptotic matching

7) Drop spreading
From coatings, inkjet printing to criminal investigations
Dynamic contact angle and contact line speed
Case of the perfect wetting: Tanner's Law
Influence of impact velocity on the maximum spreading diameter
The different impact regimes

8) Techniques to measure surface tension
This case study includes a practical work. It is carried out at the Laboratoire de Génie des Procédés et Matériaux (EIFFEL building, Univers Vivant). Two techniques for measuring surface tension are implemented and analysed in depth:
- The drop weight method (or stalagmometry)
- The pendant drop method.

Miniproject (9h+2h)

The mini-project is carried out in groups of 3 to 4 students. Each miniproject is part of a theme (related to the physics of divided matter) and focuses on a specific phenomenon, system or object. The student apply and deepen the various concepts previously discussed in class but also explore other aspects of the physics of divided matter. As an example, for the academic year 2019-2020, the themes chosen by the students were: The ascent of sap in trees, Surface phenomena used by carnivorous plants, Marangoni busrting, The cavitation bubble of the snapping shrimp. Starting from the selected theme, each group has to

- address an issue,

- carry out and present a “kitchen experiment” to illustrate the theme and/or the problem
- identify the physical mechanisms involved in the focused problem
- optionally: design an experiment to investigate the problem, carry out a test campaign, analyze the experimental results and propose a simple model that accounts for the results OR develop a more complex model, implement it on the computer, run a parametric study and discuss the results.

The deliverables are :
- A ppt file that reports on the work done (the support of the oral presentation + appendices detailing the experiments, calculations, list of bibliographical references)
- A 20 min oral presentation with a demonstration of the code or a movie of the running experimental set-up, followed by 10 min of questions (duration adjusted for the number of groups)

Class components (lecture, labs, etc.)

The course is divided into three parts (see Contents for more details): 12 hours of lectures and related tutorials, 12 hours devoted to case studies (including 3 hours of practical work), 11 hours dedicated to the realization of a miniproject.

Grading

Continuous assessment (mark out of 6, based on the notes delivered after each case study) + Course project (mark out of 14, based on ppt file + oral presentation + answers to questions)

Course support, bibliography

- Provided course material: lecture slides, problem statements and solutions
- References:

- P.G. de Gennes, F. Brochard-Wyart and D. Quéré, Capillarity and Wetting Phenomena: Drops, Bubbles, Pearls, Waves, Springer, New York, 2004.
- J. Israelachvili, Intermolecular and surface forces, Academic Press, Elsevier, 3rd edition, 2011.
- E. Guyon, J.P. Hulin, L. Petit, Hydrodynamique physique, EDP Sciences, 3ème édition, 2012.

Resources

- Teaching staff (instructor(s) names): Hervé Duval, Marie-Laurence Giorgi, Jacopo Seiwert
- Maximum enrollment (default 35 student): 35
- Software, number of licenses: ImageJ (open source), python and the libraries scipy, matplotlib and numpy (open source)
- Equipment - specific classrooms (specify the department and room capacity): none

Learning outcomes covered on the course

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

- List and explain the mechanisms and physical phenomena involved in the most common dispersed systems, from industry or daily life;
- Define and calculate the associated characteristic length- and time scale;
- Interpret the dynamic behaviour of any dispersed system;
- Construct a model that captures the essence of the physical phenemona that take place in a dispersed system
- Propose an experimental setp-up/protocol to validate this model

Description of the skills acquired at the end of the course

C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem.
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem.
C1.3 : Solve problems using approximation, simulation and experimentation.
C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.