Light, Liquids and Interfaces

Micro-390

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Spring semester

IMN10 10.15 -12.00 [Tuesday]
CM013 10.15-12.00 [Thursday]

Teaching Assistants:

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Why this course?

Interfaces are part of any material, and it is at these locations that important chemistry and physics happens. Often the macroscopic properties of a material depend on it. Many of these interfaces are in contact with liquids, of which water is the prime example on planet earth. For example, the human body consists for 60 % of water. A cell contains DNA, proteins, lipids, peptides, salts, sugars and other types of molecules and macromolecules. A cell is a crowded space; viewed from a single macromolecule, there is on average a mean free path of 1-2 nm before the molecular boundary or interface with another object, macromolecule or organelle, is encountered. Therefore, in order to understand processes in living matter it is essential to know how to analyze the types of interactions that occur between water molecules, and in aqueous solutions but also at complex realistic interfaces.

Apart from the interface and interactions of a macromolecule with its surroundings there are also larger scale interfaces, such as cell and organelle membranes. Although the total mass percentage of this interfacial material is only a few % of the human body, the interfacial area can be huge: a cell with a typical radius of 10 μm, can have 110000 μm^2 of interfacial area. Thus, apart from molecular interactions it is also necessary to understand how these interactions add up on the interfacial length scale, and how they can be retrieved from measurements.

The aim of this course is to provide understanding, recognition, organization and quantification of molecular forces and interactions in liquids and at interfaces. You will be able to analyze a molecule, a solution or an interface and determine what the important characteristics are. We will see how the intermolecular interactions between many molecules are coming together on an interface and how interfacial properties can be measured. We will pay special attention to electrostatic interactions. The acquired understanding and skills are needed when a liquid material or chemical system needs to be analyzed. Examples are the solvation of small and large molecules, the folding and unfolding of proteins, the self-assembly of lipid membranes, or the separation of different biochemical components. Another application is in the engineering of artificial materials for transplantation or the design of new nanomaterials or medicinal compounds or carriers.

This course will also provide knowledge about spectroscopic techniques that can be used to understand the molecular properties of liquids and their interfaces. We will in particular discuss infrared spectroscopy, Raman spectroscopy, second harmonic scattering and sum frequency scattering, including new state of the art developments.

In addition to learning about interactions, water, interfaces and methods to probe them in-situ, this course aims to provide instructions and exercises on how to deal with the unknown. To do that, most of the exercises require a certain routine for solving them, which is the same routine that is useful for solving research questions.

Broadly speaking in most questions the following tasks need to be performed:

- Define the physics laws and system concepts that are appropriate for this question.
- Write / compute / derive an expression for the physical property we are looking for in terms of parameters that can be measured.
- Fill in appropriate numbers and compute a value.

There are ~40 exercises to give the chance to practice this problem solving procedure. It is highly recommended that you take the opportunity offered during the class and come to the lectures. Statistically, it turns out that students who do not follow the lectures will have significant difficulty with picking up the taught skills. The material taught here is understood rather by practice than by memory.

Course Material

Molecular processes in the liquid environment of the cell are intriguing and complex. We can nevertheless obtain insightful understanding if we consider only the essentials. This can be achieved by making useful approximations. Interactions can often be approximated by interactions between charges, dipoles or polarizable objects.

During the course we will study these interactions and put them in a general framework that is useful for understanding any liquid or liquid mixture. We will also see how these interactions may lead to aggregation and 3D self-assembly and what determines the formation of micelles, liposomes and other structures. We will use the following book:

Jacob N. Israelachvili
Intermolecular and Surface Forces, Third Edition, 2011 Elsevier Inc.
ISBN: 978-0-12-375182-9

And parts of:
Dor Ben-Amotz, Understanding Physical Chemistry 1st Edition, 2013, Wiley.
ISBN: 978-1-118-71939-8
Peter W. Atkins and Julio de Paula, Physical Chemistry 8th Edition, 2006, Oxford University Press
ISBN: 9780198700722
H. Ohshima, Theory of colloid and interfacial electric phenomena, 1st edition, 2006, Elsevier, ISBN: 978012370642

These books have been made available on the moodle (PDF).

The following table shows an expected layout of the course material (adjustments may occur during the lecture). The untagged chapters refer to the book written by J. N. Israelachvili.

Table 1: Planned lecture material

Topics	Material
1. Introduction and numerical aspects	Notes, Chapter 1
Probability and thermodynamics	Notes, Ben-Amotz, Chapter 1 + notes
2. Driving forces in biological systems	Notes, Chapter 2: paragraphs: 2.1 - 2.4, 2.6, 2.7
	Notes, Chapter 3: paragraphs: 3.1 – 3.8
	Notes, Chapter 4: paragraphs: 4.1 – 4.7; 4.9-4.11
	Notes, Chapter 5: paragraphs: 5.1 - 5.4; 5.6;
	Notes, Chapter 6: paragraph: 6.1;
	Notes, Chapter 7: paragraph: 7.1-7.3;
3. Water	Notes, Chapter 8: 8.1; 8.2; 8.5-8.7
4. Spectroscopy of liquids	Notes, Atkins 9.4,9.5 (Vibr. Motion); 13.1,13.2; 13.9; 13.13,13.14;13.15;13.16
5. Interfaces in 2D and 3D	Notes, Atkins Ch. 19.15; Ohshima, CH1:1-2;3.1.1-3.1.2.;
6. Techniques to probe interfaces	Notes
7. State of the art	Notes

As an aid to the students hand written teacher notes & video recordings of the lecture will be made available on the moodle. They are meant as an aid and should not be seen as a replacement of the book.

Course Layout

The course is specified as 2H + 2H lecture and exercise.

Course Coordinates: Where & When

The room for the course is IMN10 10.15 -12.00 [Tuesday] and CM013 10.15-12.00 [Thursday]
The time: 14 weeks, starting Feb 18. During the class you will need to bring paper to make notes and exercises on. A pocket calculator is useful too.

Background knowledge

During the course concepts from other lectures will be used. Concepts and methods such as Gibbs free energy, entropy, probability, Taylor series, partial integration, differentiation, Gauss law, and the ideal gas law will be used during the course. Basic knowledge of the structure of simple chemicals and biomolecules will also be taken for granted. These concepts have been introduced in the bachelor program during the first two years of materials science study.

Table 2: Background material from MX bachelor program

Course	Concepts
Analysis I-IV	Probability, Taylor series, partial integration, differentiation
Lin Algebra	Vector calculus
Gen. Physics	Work, energy, forces
Electrical Engineering	Electrostatic potential, E-fields, current
Adv. Gen. Chemistry	Structure of chemicals and biomolecules
Thermodynamics for materials science	Laws, State functions, chemical potential & equilibrium
Biology for engineers	Lipids, water, macromolecule structure
Surfaces and Interfaces	Def. of surface tension, Contact angles / Young equation
	Laplace equation, nucleation, Kelvin equation, Ostwald ripening
	Adsorption at interface (BET, Langmuir)
	Thermodynamics of liquid interface
	Electric double layer theory & Debye Hückel Theory
Theory of materials	Thermodynamics, Dielectric constant, Symmetry
Functional properties of materials	(IR) Spectroscopy

Communication:

There is a moodle for this course: http://moodle.epfl.ch/course/view.php?id=13711. Key: plasmon-391.
On the moodle the necessary course material and instructions can be found, which will be kept up to date by the TAs.

Examination and grading:

There will be an exam before the spring semester. During the autumn semester there will be an opportunity to test your knowledge: In the middle of the semester an intermediate test, consisting of two questions will be given. The test will be conducted exactly like an exam and will be graded. The question with the best score can be used to replace the question you have scored worst on during the exam. The participation to the midterm test is voluntary; students who do not take the midterm test can obtain the maximum grade for the class (6) based on the final exam only.