SSM
Scuola Superiore Meridionale

Course title:

Physics of matter from the zepto-scale to the macro-scale

Duration [number of hours]**: 24**

PhD Program [MERC/MPHS/SPACE]**: MPHS**

Name and Contact details of unit organizer(s):

Prof. Lorenzo Marrucci, Prof. Fabio Ambrosino, Prof. Rosario Fazio, Università di Napoli Federico II, Dipartimento di Fisica "Ettore Pancini", lorenzo.marrucci@unina.it, Fabio.Ambrosino@na.infn.it, rosario.fazio@unina.it

Course Description [max 150 words]**:**

An introductory "crash-course" in quantum modeling of matter at spatial scales ranging from the elementary-particle "zepto-scale", through nuclei, atoms and molecules, up to macro-scale quantum-based emergent properties of condensed matter. The course will be primarily aimed at students with a non-physics background (e.g., mathematics and engineering students), although we hope physics students may still find it useful.

Syllabus [itemized list of course topics]**:**

Part 1: Foundations
Lecture 1: The mathematical structure of quantum physics
Lecture 2: A single quantum particle: quantum wells, harmonic oscillator, tunneling
Lecture 3: Atoms, molecules, photons and their interactions
Lecture 4: Solids and electronic bands, entanglement and correlations, bosons and fermions, Fock states

Part 2: Subnuclear and nuclear scales
Lecture 5: Building blocks : leptons and quarks. Symmetries and multiplets.
Lecture 6: Interactions and mediators. S-matrix and Feynman diagrams. Gauge Bosons.
Lecture 7: The Standard Model picture. The role of the Higgs field.
Lecture 8: Nuclear forces and nuclear models. Radioactivity and stability.

Part 3: Macro scales and emergent phenomena
Lecture 9: Emergent phenomena - (quantum) magnetism
Lecture 10: Emergent phenomena - superconductivity and superfluidity
Lecture 11: Quantum synthetic matter
Lecture 12: Macroscopic quantum dynamics

Assessment [form of assessment, e.g., final written/oral exam, solutions of problems during the course, final project to be handed-in, etc.]**:**

For the final exam, the students are asked to prepare an oral presentation on a specific topic related to the course. They will also have to answer to questions which start from the presentation and may touch on the material presented in the course.

1) The presentation can be on any topic related to the course which has not been studied previously by the student (at least not at the same level of depth).

2) The topic of the presentation can be proposed by the students themselves, but it must be approved in advance by one of the instructors. Alternatively, if requested, the instructors can propose a theme to the students.

3) The presentation must be about 30 minutes long. It can be done with the help of slides, in the presence of all three instructors if possible, or at least of two of them.

4) The presentation will be followed by questions by the instructors, which start from the presentation but can range over the entire course content.

Suggested reading and online resources:

Some sections of this open online textbook can be used for background material on part of the course:
http://eng-web1.eng.famu.fsu.edu/~dommelen/quantum/style_a/index.html

It is highly recommended that students study the section II.2 (mathematical prerequisites) before the start of the course.

Additional material will include the course slides and, possibly, other textbooks to be defined.

Course title:

Soft Matter Modelling: Molecular Simulations and Soft Matter in Flow

Duration [number of hours]**: 24**

PhD Program [MERC/MPHS/SPACE]**: MPHS**

Name and Contact details of unit organizer(s):

Prof. Giuseppe Milano, Prof. Pier Luca Maffettone, Prof. Massimiliano Maria Villone
Affiliation(s): UNINA
Website: www.docenti.unina.it/giuseppe.milano ,
Email: giuseppe.milano@unina.it
Website: www.docenti.unina.it/pierluca.maffettone,
Email: p.maffettone@unina.it, massimilianomaria.villone@unina.it

Course Description [max 150 words]**:**

"Soft Matter" (or complex fluids) is ubiquitous in many technological and industrial processes. This course has two parts, the first introduces the basics of molecular simulations and will give example applications of this class of techniques to typical soft matter materials including atomistic and coarse-grained modelling approaches. The second part is focused on Soft Matter under flows. Soft matter can flow like liquids, it possesses a measurable viscosity, can bear stresses, and typically shows viscoelastic behaviour under flow conditions. A common characteristic is its large and nonlinear response to weak forces. This course introduces the fluid-dynamics of viscoelastic liquids. Rheological models for macromolecular systems will be presented. Introduction to Brownian Dynamics computations with Matlab will be given.

Syllabus [itemized list of course topics]**:**

- A first introduction to Molecular Simulations (1 h)
- Basics of Statistical Mechanics for Molecular Simulations (3 h)
- Molecular Dynamics: integration, force calculations (1 h)
- Monte Carlo: from Monte Carlo integration to Metropolis (2 h)
- Force Fields (1)
- How to increase simulation speed: main algorithms, coarse-graining (3h)
- Molecular Simulations: some example applications (1h)
- Introduction to Soft Matter and Continuum Mechanics (2h)
- Introduction to Brownian Dynamic simulations (2h)
- Rheology (2h)
- Modelling flexible and rigid macromolecules dynamics (3h)
- Brownian Dynamic simulation of flexible and rigid macromolecules (3h)

Assessment [form of assessment, e.g., final written/oral exam, solutions of problems during the course, final project to be handed-in, etc.]**:**

Team's work on a project
Final discussion on all the reports

Suggested reading and online resources:

Suggested books:

1. Frenkel and Smit, *Understanding Molecular Simulations: From Algorithms to Applications*, Academic Press, 2023
2. Larson RG, *The structure and rheology of complex fluids*, Oxford University Press, 1999
3. Doi M, *Soft Matter Physics*, Oxford University Press, 2013