UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Structure of Matter

2627-2-E30004Q012

Aims

The course will allow the students to understand the fundamental properties of atoms, molecules and solids and show how to apply the principles of classical and quantum physics to describe their main aspects.

Students will develop a deep understanding of the electronic properties of atoms, molecules and solids and of the nuclear motions in molecules and solids. They will learn how to derive the response functions to external electric and magnetic fields as well as acquire a suitable knowledge of the main spectroscopies used to study those systems.

Emphasis will be placed on the theoretical approaches used to describe the structure of matter, on the experimental study of atoms, molecules and solids and on the relevance of these properties of matter for different technologies.

Upon successful completion of this course, students will be able to:
• Apply theoretical approaches to solve problems involving atoms, molecules and crystals.
• Understand which are the most suitable spectroscopies to study the different properties of matter.
• Understand the thermodynamic properties of matter and the response functions to electric and magnetic fields.
• Apply quantum mechanics to various physical systems.

Learning outcomes:
DdD1 Knowledge and understanding – Students will acquire a deep knowledge of the basic properties of atoms, molecules and solids.

DdD2 Applying knowledge and understanding – Students will be able solve problems on real systems, including some of technological relevance, by applying the theoretical framework and the main physical concepts they have learned during the course.

DdD3 Making judgments – By solving problems, by making group presentations or by using dedicated apps, students will develop the ability to choose the best strategies and the most suitable theoretical and mathematical

instruments to find the solutions to a given problem.

DdD5 Learning skills - The blended didactic organization requires the students to use multimedia, develop autonomous study and adaptivity, managing time, materials and exercises, as well as the ability to make team work and presentations. This will allow to gain both the soft as well as the hard skills that will be necessary not only to learn more advanced topics but also methodologies useful for permanent education.

Contents

The fundamental properties of atoms, molecules, and solids will be presented, along with their response functions and with the methodologies which allow one to investigate the main properties of these different forms of aggregation of matter.

Detailed program

- Statistical mechanics: Boltzmann, Fermi-Dirac, and Bose-Einstein distributions.
- Hydrogenic atoms: finite mass effects, spin-orbit interactions, and Rydberg atoms. The Alkali atoms.
- The Helium atom and the exchange interaction. The LS scheme. Hyperfine interactions.
- Polarizability and magnetic susceptibility of an ensemble of atoms.
- Electronic states in molecules: MO-LCAO method, hybrid orbitals, the benzene molecule.
- Motions of the nuclei in molecules: rotational and vibrational motions, and indistinguishability effects.
- Crystal structures and reciprocal lattice.
- Electronic states in crystals and fundamental models to describe the electron dispersion curves. Transport properties.
- Bonding mechanisms in crystals.
- Lattice vibrations and models to describe the thermodynamic properties of phonons in crystals.

Prerequisites

It is important to know the fundamental aspects of mechanics, thermodynamics, electromagnetism, and quantum mechanics. It is also useful to know the basics of statistical mechanics.

Teaching form

Lectures will be held in a hybrid format, with classroom lectures and asynchronous video lectures, which will be made available on the e-learning platform. During the lessons, the program topics will be covered and problem-solving will be used to illustrate the application of what was learned during the lectures. Software that fosters greater student interaction and participation will be used during the classroom lessons. Team work will also be offered.

Textbook and teaching resource

In addition to the asynchronous video lectures, video recordings of the lectures in the classroom, presentation slides, solutions to problems solved in class, and other useful teaching materials will be made available on the e-learning platform.
The reference textbook is A. Rigamonti, P. Carretta, *Structure of Matter: an Introductory Course with Problems and Solutions*, Springer, 2015 (third edition). The topics covered during the course are covered in Chapters 1 through 14 of the book. The sections of the book which are useful for preparation purposes will be specified in the e-learning platform.

Semester

Second semester (from the 1st of March 2027)

Assessment method

Assessment is based on group work on one of the topics proposed by the professor and on a final oral exam. For the oral exam, students are advised to focus on aspects common to the discussions of atoms, molecules, and solids. For example, students must be able to explain the effect of static electric fields on the properties of atoms, molecules, and solids, or be able to discuss the effects associated with particle indistinguishability in atoms, molecules, and solids due to exchange, or describe the spectroscopies used to determine the properties of atomic, molecular, and solids. It is also very important to know or to be able to evaluate the orders of magnitude of the various observables.

Office hours

The appointment can be fixed by sending an email to the professor.

Sustainable Development Goals

QUALITY EDUCATION