UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Structure of Matter

2425-3-E3001Q057

Aims

Understanding the properties of atoms, molecules and solids by means of quantum mechanics and statistical mechanics.

Contents

Elements of classical and quantum statistical mechanics.

Atoms: two-electrons atoms, many-electron atoms in the Hartree theory and the periodic table.

Molecules: electronic states and the chemical bonding of diatomic and polyatomic molecules, molecular rotations and vibrations, molecular spectroscopy.

Solids: band theory of electrons in crystals, electrical conduction in metals, semiconductors and semiconductor devices.

Detailed program

The course consists of four sections after an introductory lecture on many particle systems.

The reference to specific chapters of the textbooks is given in each section.

Quantum Mechanics of Many Particles Systems

(**(CT)**, chapter 14)

Identical particles: Fermions and Bosons, Slater determinant for independent particles, Pauli exclusion principle.

Statistical Physics

(**(KK)** chapters 2, 3, 6-9 or equivalently **(T)** chapters 1, 2.1-2.4, 3.4-3.5.3, 3.6.1-3.6.3 or **(M)** chapter 4)

- Entropy, temperature and probability.
- Canonical ensemble and the Boltzmann distribution.
- Ideal classical gas.
- Chemical potential, gran canonical ensemble and the Gibbs distribution.
- Quantum distributions functions: Fermi-Dirac and Bose-Einstein distributions.
- Degenerate Fermi gas: Fermi energy, specific heat.
- Low temperature Bose gas and the Bose-Einstein condensation, superfluid Helium.

Atomic physics

(**(BJ)** chapters 7 and 8)

- Two-electrons atoms: perturbation theory and variational principle for the ground state.
- Exited states of two-electrons atoms: parahelium and orthoelium.
- Many-electron atoms in the Hartree theory.
- Ground state of many-electron atoms and the periodic system of the elements.
- Corrections to the central field approximation: L-S and j-j couplings, Hund's rules.

Molecular Physics

(**(M)** chapter 3, **(BJ)** chapters 10 and 11)

- The Born-Oppheneimer approximation.
- The electronic structure of the H2 molecule: the Heitler-London and the molecular orbital schemes.
- Electronic states in homo- and hetero-nuclear diatomic molecules, covalent and ionic bonding.
- Electronic states in polyatomic molecules: hybridization and the Hueckel model.
- Rotations and vibrations of diatomic molecules.
- Raman and IR spectra of the diatomic molecule. IR selection rules in the electric dipole approximation.
- The effects of the nuclear spin on the rotation of the homonuclear diatomic molecules.
- Specific heat of polyatomic molecules. The theorem of equipartition of energy.

Solid State Physics

(**(M)** chapter 5)

- Lattices and crystal structures.
- Diffraction experiments and the reciprocal lattice.
- The band theory of electrons in crystals: metals and insulators.
- Semiclassical dynamics of electrons in crystals and the electrical conductivity of metals.
- Semiconductors: distribution of electrons and holes in intrinsic semiconductors, n and p doping, acceptor and donor states in the hydrogenic model.
- Semiconductor devices: the pn junction.
- The laser. (**(M)**, section 4.4.1)

Prerequisites

Mathematics and physics courses of the first two years. The first part of the course of Quantum Mechanics.

Teaching form

Frontal lessons for 7 cfu (56 hours).
Exercises (frontal not interactive) for 1 cfu (12 hours).
Lessons and exercises will be given in Italian.

Textbook and teaching resource

- C. Cohen-Tannoudji, B. Diu, F. Laloe, Quantum Mechanics, volume II, J. Wiley & Sons **(CT)**

- C. Kittel e H. Kroemer, *Thermal Physics* (W. Freeman, 1980) or the Italian edition, *Termodinamica Statistica*, Boringhieri (Torino 1985). **(KK)**

- N. Manini, *Introduction to the Physics of Matter*, (Springer, 2014), available in e-book on the library website. **(M)**

- B. H. Bransden & C. J. Joachain, *Physics of Atoms and Molecules,* 2nd edition, (Harlow – Prentice Hall, 2003). (BJ)

- D. Tong, Lectures on Statistical Physics, http://www.damtp.cam.ac.uk/user/tong/statphys.htm. **(T)**

for further details on special topics

C. Kittel, Introduction to Solid State Physics, 8th edition, Wiley (2005) or the italian edition published by Editrice Ambrosiana.

H. Haken and H. C. Wolf, Molecular Physics and Elements of Quantum Chemistry, Springer, available in e-book on the library website. Cap. 4, 5, 9-13.

Semester

First and second semester.

Assessment method

Students are evaluated through a written exam followed by an oral one.

Written exam with exercices.
The written exam lasting 2.0 hours consists of three numerical exercises on topics of statistical mechanics, atomic and molecular physics and solid state physics.

The written test is aimed at evaluating the ability to apply the principles and techniques illustrated in class in the solution of simple numerical exercises.

The use of books and minute is NOT allowed during the written exam. Only the use of an electronic calculator is permitted, all other electronic devices are forbidden.
It is possible to use a formulary consisting of a single A4 page, double sided, to be written on a white sheet either printed or with a red pen to make it distinguishable from the other sheets used to write the solution of the problems. The name of the student must be written on the formulary.

To be admitted to the oral exam a minimum of one exercise correctly solved or fractions of exercises that sum to one are requested. A mark of 18 points will be given for the first exercise correctly solved. A mark of 6 points will be given for each other exercise correctly solved.

The oral exam will be focused on the discussion of the written exam and on the topics of the lessons.
The ability to present the topics covered in class in all their conceptual and formal aspects will be assessed, including the derivation of the results.

The oral exam must be scheduled in the same session of the written exam.
Erasmus students can take the oral exam in English.
No ongoing partial tests are planned.

Office hours

At 17:30 pm or at 15:30 on the days on which a lecture ending at those hours is scheduled.

By appointment in the periods with no lessons.

Sustainable Development Goals

QUALITY EDUCATION