UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# SYLLABUS DEL CORSO

## Elementi di Meccanica Quantistica e Struttura della Materia

**2526-2-ESM01Q010**

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### Aims

1. Knowledge and understanding (DnD 1).
   The course aims at introducing and developing the basic concepts of quantum mechanics employed to model the properties of matter at the atomic level.

2. Applying knowledge and understanding (DnD 2).
   The formal tools needed to understand the knowledge acquired at point 1 will be provided to the students to be applied in the understanding and use of some fundamental aspects of matter, such as spin, the fine structure of the hydrogen atom, the electronic structures of multi-electron atoms, and light-matter interaction.

3. Making judgements (DnD 3).
   Several hours of exercises with the teacher will be provided to prepare the written part of the exam, as well as a simulation of the written test to self asses the preparation.

4. Communication skills (DnD 4).
   Each lecture includes an open discussion with the lecturer to verify and deepen the acquired knowledge, the critical ability to identify the most crucial information to presented an communicated at the oral part of the exam.

5. Learning skills (DnD 5).
   The exercises discussed during the lecture will be complemented with extra exercises and discussion proposed by the students to verify their ability to go further explore the topics covered and to prepare the examination.

### Contents

PART 1:

- The crysis of classical physics
- The quantum Particle
- The Schroedinger equation
- The hydrogen-like atom

PART 2:

- General formalism of quantum mechanics
- Electron spin
- Approximate methods
- Spin-orbit interaction
- Fine structure of the hydrogen atom
- Zeeman effect
- Many-particle formalism
- He atom
- Many-electron atoms
- Light-matter interaction

## Detailed program

PART 1
THE CRISIS OF CLASSICAL PHYSICS
Black body spectrum, classical theory and Planck's proposal; the quantum of energy. Photoelectric effect, apparatus and experimental observations; classical interpretation and quantum interpretation. Corpuscular model of light; the photon. Compton effect: experimental aspects and interpretation. Production and annihilation of e-and + pairs. Spectrum e.m. and photon-matter interaction. Bohr model: construction and results; consequences. Transitions and spectra. Franck-Hertz experiment and interpretation. Hypothesis of De Broglie; Davisson and Germer and Thomson's experiments.

THE QUANTUM PARTICLE
Wave function ? and wave equation for matter waves. ? as a harmonic wave or as a package. Advantages of the package; uncertainty principles. Recalls on wave packet, group velocity, Fourier transform, Gaussian packet. Discussion and consequences of the uncertainty principles. Born's probabilistic interpretation of the wave function ?. Measurement and expectation values. Operators and representation rules; examples.

THE SCHRÖDINGER EQUATION
Schrödinger's equation: derivation, meaning, properties. Current density of probability and conservation. Separation of variables, eq. Schrödinger's at stationed states. Eigenstats and eigenvalues of H. Probability and energy of a stationary state. Probability and energy of non-stationary states; charge density. Solution of eq. Schrödinger's 1D: the quantum particle in a well of infinite potential. Eigenstates and energies. Examples of an infinite hole; consequences. The quantum particle in a 3D infinite hole. Degeneration. Finite potential hole: odd and even solutions and energies; solutions and continuum states; reflection and transmission. Characteristics of infinite and finite hole, with discussion of problems. Potential step and potential barrier 1D. Reflection and transmission coefficients, probability current density. Tunnel effect. 1D harmonic oscillator: solution of Eq. Schrödinger's, stationary states, energies. Potential with a minimum: bound and continuum states.

ATOMS
Schrödinger equation for a particle in the central field; angular and radial equation. Radial and angular probability density. Solution of Eq. radial; functions Rnl (r), principal quantum number n and energies En. Solution of Eq. angular; the spherical harmonics Ylm (?, ?) and their properties. Quantum numbers orbital l and magnetic m. The

general solution ?nlm = Rnl (r) Ylm (?, ?). Electric dipole transitions and selection rules. Angular momentum and its quantization; eq. to the eigenvalues of L and Lz, classical limit. Hydrogen-like atom

PART 2
FORMALISM OF QUANTUM MECHANICS
Hilbert spaces, operators associated with physical observables, indetermination theorem, constant of motion, Ehrenfest theorem.

ELECTRON SPIN
Orbital magnetic moment, Ster and Gerlach experiment, spin magnetic moment, Pauli matrix, spin quantum number and formalism extension.

APPROXIMATE METHODS
static perturbation theory for non-degenerate and degenerate levels, variational principle.

SPIN-ORBIT INTERACTION
spin-orbit interaction term, total angular momentum operator.

FINE STRUCTURE OF THE HYDROGEN ATOM
spin-orbit correction to the electronic levels, relativistic correction.

ZEEMAN EFFECT
Level splitting in the presence of a magnetic field, strong and weak Zeeman effect.

MANY-PARTICLE FORMALISM
Identical particles, Slater determinant, Pauli esclusion principle.

He ATOM
ground state by neglecting electron-electron repulsion, perturbative and variational correction, single and triplet states, Hartree and exchange integrals

LIGHT-MATTER INTERACTION
time-dependent perturbation theory, electric dipole approximation, absorption, stimulated and spontaneous emission

## Prerequisites

Suggested prepararation:
Physics I, Physics II, Matematics I, Matematics II and Matematics III

## Teaching form

The course language is Italian.

PART 1:
24 hours, didactic (face-to-face) lectures.
24 hours, interactive teaching (face-to-face lectures).

PART 2:

24 hours, didactic (face-to-face) lectures.
24 hours, interactive teaching (face-to-face lectures).

## Textbook and teaching resource

Notes and suggested textbooks.

main textbooks:
*The Physics of Atoms and Quanta* Introduction to Experiments and Theory, Haken, Hermann, Wolf, Hans Christoph Editor: Springer
*Quantum Mechanics*, L. Del Debbio and A berera

complementary book:
*Fondamenti di Fisica Atomic e Quantistica*, Franco Ciccacci, Editor: Edises
*Introduction to Quantum Mechanics*, David J. Griffiths.

## Semester

2° semester.

## Assessment method

The exam will be divided into a written part and an oral part.
Students must first demonstrate, in a written test usually consisting of four exercises, that they possess the formal tools for managing and utilizing the basic concepts of quantum mechanics and the structure of matter. After the written test, the exam includes an oral interview aimed at assessing the level of knowledge acquired on the entire program.

PARTIAL EXAMINATIONS
During the course, it will be possible to take two partial exams, each focused on the content of the two course modules. Each partial exam includes a written test consisting of two exercises, in which students must demonstrate that they possess the formal tools for handiling and utilizing the concepts illustrated during the first or second part of the course (Module 1 or 2). After the written test, the partial exams include an oral interview aimed at assessing the level of knowledge acquired on the respective parts of the program (Module 1 or 2).

The overall evaluation will be calculated as the arithmetic mean of the grades received in the two partial exams.

## Office hours

By appointment.
Please write to the lecturers at the following e-mail addresses:
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**Sustainable Development Goals**