UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Elements of Quantum Mechanics and Structure of Matter

2627-2-ESM02Q010

Aims

The course aims at giving the knowledge and teaching the practical use of the basic concepts of quantum mechanics, showing the radical evolution from classical physics, that are needed to describe and understand the atoms, molecules and condensed matter structure and properties.

In details, the course has the following 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 textbook:
The Physics of Atoms and Quanta Introduction to Experiments and Theory, Haken, Hermann, Wolf, Hans Christoph Editor: Springer

complementary text book:
Quantum Mechanics, L. Del Debbio and A. Berera

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.

Upon request, students may take the examination in two separate partial exams, each covering one of the two parts of the course. Each partial exam consists of a written test with two problems, in which students must demonstrate their command of the formal tools required to address and apply the concepts covered in the relevant part of the course. The written test is followed by an oral examination aimed at assessing the level of knowledge acquired for the corresponding part of the syllabus.
The final grade will be determined on the basis of the grades obtained in the two partial exams. If their arithmetic mean is not an integer, the final grade will be determined jointly by the instructors, taking into account the student's overall performance in both examinations and the level of preparation demonstrated.

The grading scale will be as follows:

• Below 18/30: Fail. The minimum required level of preparation has not been achieved.
• 18–21/30: Knowledge of a limited number of topics included in the course syllabus. Limited ability to discuss and

analyse the material, emerging only with guidance and questions from the instructor. Communication skills and use of terminology are not always accurate; critical thinking ability is limited.
• 22–24/30: Knowledge of part of the topics included in the course syllabus. Limited ability to analyse material independently; generally correct, although not always precise or clear, use of terminology; presentation skills may at times be uncertain.
• 25–27/30: Knowledge of a broad range of topics covered in the course syllabus. Ability to develop arguments and conduct critical analysis independently, and to apply knowledge to specific cases. Correct use of terminology and competent use of disciplinary language.
• 28–30/30 cum laude: Complete and thorough knowledge of the examination topics. Demonstrated personal ability to discuss topics independently and analyse them critically; excellent independent and critical thinking; full command of disciplinary terminology and a rigorous, well-structured presentation.

Office hours

By appointment.
Please write to the lecturers at the following e-mail addresses:
angelo.monguzzi@unimib.it
emilio.scalise@unimib.it

Sustainable Development Goals