UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Meccanica Quantistica

2526-1-F4002Q017

Aims

Aims of the course in Terms of the Dublin Descriptors

1. **Knowledge and Understanding**
   At the end of the course, the student will have acquired a solid understanding of the fundamental principles of quantum mechanics, including the postulates, the mathematical formalism, and the role of symmetries. They will be able to recognize the experimental evidence that requires a quantum description and justify the need to go beyond classical physics.

2. **Applied Knowledge and Understanding**
   The student will be able to solve simple problems such as the potential well, step, barrier, harmonic oscillator, and hydrogen atom, and use mathematical tools to analyze quantum systems of increasing complexity.

3. **Independent Judgment**
   The student will develop the ability to critically evaluate the implications of quantum formalism, gaining a conceptual understanding of the epistemological revolution introduced by quantum mechanics and its consequences regarding the surpassing of classical physics.

4. **Communication Skills**
   The student will be able to clearly and rigorously express the concepts of quantum mechanics and effectively communicate their solutions and arguments, even in interdisciplinary contexts.

5. **Learning Skills**
   The student will have acquired the theoretical and methodological tools to continue studying advanced theoretical physics (such as quantum field theory and condensed matter physics), developing autonomy in studying and understanding new problems and models.

Contents

- **Fundamentals of quantum physics**: states, operator and postulates of quantum physics
- **Quantum properties**: operators, indetermination principle, basics of quantum information
- **Canonical quantisation and quantum mechanics**: momentum and position operators, Noether's theorem
- **Time evolution**: Schroedinger equation, Shroedinger and Heisenberg representations
- **One-dimensional quantum mechanics**: free particle, wave packet, potential well, potential step, potential barrier, harmonic oscillator
- **Multi-dimensional quantum systems**: tensor product spaces, separable potentials, two-body problem
- **Angular momentum**: Lie groups and Lie algebras; rotation group, angular momentum, spin, composition of spin and angular momenta
- **Three-dimensional problems**: radial Schroedinger equation, Coulomb potential and the hydrogen atom
- **Action in quantum mechanics**: path integral and Feynman approach

Detailed program

Course Learning Outcomes in Terms of the Dublin Descriptors

1. **Knowledge and Understanding**

Upon completion of the course, students will:

- Demonstrate a clear understanding of physical phenomena that challenge classical theories, justifying the need for quantum mechanics.
- Comprehend and articulate the postulates of quantum mechanics, including key concepts such as quantum states, operators, and observables.
- Understand the role of the uncertainty principle and the mathematical structure underpinning compatible and incompatible observables via commutators.
- Grasp the formalism of the density matrix and its role in describing quantum states and measurements.
- Explain Noether's theorem and its significance in quantum systems, particularly in relation to symmetries and conservation laws.
  Understand the mathematical and physical properties of position and momentum operators, and the formulation of the Schrödinger equation.
- Analyze solutions to one-dimensional quantum systems such as potential wells, steps, barriers, and harmonic oscillators.
- Understand the generalization of quantum mechanics to systems in higher dimensions, including angular momentum and rotational symmetry.
- Describe the application of group theory to quantum systems, particularly the rotation group and its representations.
- Understand three-dimensional problems such as the hydrogen atom and be introduced to path integral formulation and its derivation of the Schrödinger equation.

2. **Applying Knowledge and Understanding**

Students will be able to:

- Solve canonical quantum mechanics problems in one and multiple dimensions using analytical methods.
- Analyze and predict the behavior of quantum systems under measurement, including changes in information content.
- Apply quantum formalism to reinterpret classical systems through the lens of symmetry and operator

methods.
- Estimate wave function profiles based on potential shapes.
- Employ techniques such as variable separation for problem-solving in higher-dimensional systems.
- Perform addition of angular momentum and spin in composite systems.

3. **Making Judgements**

Students will:

- Be able to critically assess the limitations of classical mechanics and the necessity of quantum theory for explaining certain physical phenomena.
- Be capable of evaluating the conceptual and mathematical tools of quantum mechanics in physical contexts.
- Form reasoned interpretations of quantum behavior and assess solutions for physical plausibility and consistency with foundational principles.

4. **Communication**

Students will be able to:

- Clearly communicate fundamental concepts and mathematical structures of quantum mechanics using appropriate terminology.
- Translate abstract mathematical formalism into conceptual insights and explain them to both specialized and non-specialized audiences.
- Demonstrate competence in expressing physical principles in written and oral formats typical of the discipline.

5. **Learning Skills**

Upon completion, students will:

- Possess the foundation necessary to pursue more advanced topics in theoretical physics, such as quantum field theory and condensed matter physics.
- Be prepared to engage with contemporary research literature in quantum physics.
- Have developed independent learning skills through problem-solving, critical analysis, and the synthesis of diverse physical and mathematical ideas.

Prerequisites

Basic knowledge of classical physics, analysis and algebra at the level of the Bachelor's programme in Mathematics

Teaching form

Lecture. Active participation will be encouraged through the discussion of examples and problems during the lessons, according to the principles of active learning and participatory learning.

Textbook and teaching resource

Main textbook

- S. Forte, L. Rottoli, "Fisica Quantistica", Zanichelli

Additional textbooks

- J. Dimock, "Quantum Mechanics and Quantum Field Theory", Cambridge
- J.J. Sakurai, J. Napolitano, "Modern Quantum Mechanics (2nd Edition)", Addison-Wesley
- Benjamin Schumacher, Michael Westmoreland, "Quantum Processes Systems, and Information", Cambridge University Press
- A. Berera e L. Del Debbio, "Quantum Mechanics", Cambridge U.P.
- J. Binney e D. Skinner, "The Physics of Quantum Mechanics", Oxford U.P.
- M. Maggiore, "A modern introduction to quantum field theory", Oxford U.P. (group theory reference)

Semester

First term

Assessment method

Oral exam based on the discussion of topics covered in class and exercises completed during the course. The starting point of the exam will be an assigned exercise to be solved at home and presented at the exam.

The exam covers the entire course program, including exercises and in-depth topics discussed during the lessons, which are an integral part of the course.

Office hours

On student request, at agreed time via email appointment

Sustainable Development Goals

QUALITY EDUCATION