# Quantum Mechanics

## Prof. Fausto Borgonovi

***COURSE AIMS AND EXPECTED LEARNING RESULTS***

The course aims to provide the student with the basics as well as the fundamental tools for the study of Quantum Mechanics. Specifically, in addition to an understanding of the conceptual crisis and the fundamental experiments that led to the formulation of Quantum Mechanics, the student must understand the axiomatic bases of the same and the knowledge of the main investigative tools. At the end of the course the student must be able to investigate from the physical-modeling point of view a generic problem of quantum physics, to determine the learned mathematical tools necessary for writing the right equations, as well as to identify the analytical and or numerical tools necessary to solve a generic quantum mechanical problem***.***

***PROGRAM***

**1 - Inadequacy of Classical Physics *:*** The Photoelectric Effect. The specific heat of solids. Blackbody radiation. Atomic Spectra. De Broglie matter waves. The Bohr atomic model.

**2 – The Schrodinger** **equation** : Wave-particle dualism. Statistical (Born) interpretation of the wave function. Stationary states. Probability conservation. Probability density current. Bound and free states. Quantum observables and their properties: position, momentum, energy.

**3 – The Heisenberg uncertainty principle**  : Compatible and incompatible observables. Minimum uncertainty wave packet and relation with the Heisenberg principle. Gedanken experiments.

**4 – Solvable models :**  Free particle. Eigenvalues and generalized eigenfunctions. Comparison with the classical case. Piecewise constant potentials in one dimension : potential step, finite and infinite potential well. Reflection and transmission coefficient. Resonant scattering. The harmonic oscillator : eigenvalues and eigenfunctions. Creation and annihilation operators. Two-body problem : Classical and quantum solution. Spherical harmonics, radial equation. The hydrogen atom. Bound states.

**5 – The Stern-Gerlach experiment :**Spin. Matrix representation of Spin operators. Commutation rules.

**6 – The physical foundations of Quantum Mechanics:** Dirac notations, ket, bra, operators, observables. Position and momentum operators. Compatible and incompatible observables. Translation operator. Continuous and discrete spectra. Time evolution operator. Schrodinger and Heisenberg representation. Ehrenfest theorem. Constants of motion. Correlation amplitude and the energy-time uncertainty relation.

**7 – Perturbation theory :** Time-independent theory for discrete non-degenerate and degenerate spectrum. Time-dependent perturbation theory. Interaction representation. Dyson expansion. Two-states problem : Rabi oscillations. Fermi golden rule. Time-dependent periodic potential. Variational method.

**8 – Theory of Angular Momentum :**  Eigenvalues and eigenvectors. Spin and Orbital Angular momentum. Finite rotations. Comparison with the classical case. Addition of Angular momenta. Clebsch-Gordan coefficients.

**9 - Emission and Absorption of electromagnetic radiation:**  Absorption, spontaneous and stimulated emission. A, B Einstein coefficients. Average life-time of an excited state.

***BIBLIOGRAFY***

1. J.J Sakurai, Jim Napolitano *Modern Quantum Mechanics ,* Addison-Wesley, San Francisco, 2011.
2. C.Cohen-Tannoudji - B.Diu - F.Laloe, *Quantum Mechanics,* Vol. I, II, Wiley and Sons, Paris, 2005.
3. L.D. Landau - L. Lifshitz, *Quantum Mechanics,* Dover New York, 2000.
4. D.J. GRIFFITHS, *Introduction to Quantum Mechanics*, Prentice Hall Inc. NJ, 1995

***TEACHING METHOD***

Frontal lectures (60 hours) and exercises (20 hours) in the final part of the course.

***ASSESSMENT METHOD AND CRITERIA***

This course includes a written and an oral test. During the written test, the candidate will be asked to solve three exercises in which it must be shown that the techniques and skills required for their resolution have been correctly applied. In practice, it is necessary to understand which approximation schemes should be used in relation to the physics of the problems presented. The evaluation of this test takes into account not only the accuracy of the obtained results but also the procedure adopted for their resolution and the logical scheme in which the problems are often schematized and based on mathematical models. The written test is considered passed, with the following admission to the oral test, if at least 2 out of the 3 exercises have been carried out satisfactorily. In order to be considered that way, the elaborate should provide a physically sound solution, that is not burdened by important physical errors, such as: use of wrong equations or incorrect dimensional analysis. During the oral test, the results of the written test will be briefly discussed, followed by a free choice argument in which the exhibition capacity, the formal language acquired as well as the presentation organization will be evaluated. The oral exam then proceeds with a series of questions aimed at ascertaining the assimilation of the main topics covered, the mastery of the subject, and the ability to connect topics and concepts presented within the course. The evaluation of the oral exam takes into account the correctness of the illustrated procedure, their rigorous logic and methodology, the effectiveness and correctness of the presentation, enhancing the assimilation and the personal reworking by the candidate. One third of the grade is made up of the free choice presentation and two thirds of the answers to the teacher's questions. The final mark is the arithmetic mean between the oral and written tests***.***

***WARNINGS AND PREREQUISITES***

Knowledge of the mathematical tools learned in the courses of Analysis and Geometry are fundamental for a good understanding of the course. The knowledge of the Hamiltonian formalism is a fundamental prerequisite too.

Prof. Fausto Borgonovi receives students during the class days from 10am to 6pm. For appointments on other dates or requests, send an e-mail to: [fausto.borgonovi@unicatt.it](mailto:fausto.borgonovi@unicatt.it)