Study plan in

Quantum Science & Technology

Master’s Degree Program in Physics – Curriculum Experimental Nano- and Bio-Physics

Overview

Quantum Mechanics, one the most important and disruptive scientific discovery of the 20th century, unfolded the inner mechanisms of matter which are exploited also in engineering everyday electronic devices. We are now around the corner of a second quantum revolution. Quantum computers or quantum tele-portation may revolutionize everyday life, exploiting intrinsic quantum phenomena, such as quantum coherence and quantum correlation, in real applications. The current challenge is to turn the ability to address and coherently manipulate single quantum objects in our sophisticated laboratories into advanced technologies available for everyday life. Quantum Technologies are recognized as one of the key enabling technologies for the near future and fostered by EU with the ten-year long QT flagship (qt.eu).

This study plan suggests a coherent path among the wide choice of courses available for training in Quantum Science and Technologies. The plan focuses on courses in which genuine quantum phenomena are studied in details and together with courses focusing on the technologies required to realize and manipulate quantum objects for applications.

We particularly encourage applications to this Study Plan from students with a background outside, but related to Physics - e.g., Engineering –. Candidates which in their B.Sc. studies missed the fundamentals of quantum mechanics and modern physics will be guided to attend specific didactical activities which will allow to fill the gap.

First Year

Laboratory of condensed matter physics

A lab course to become familiar with a few of the most used experimental techniques in material research (electron microscopies, X-ray diffraction and electronic spectroscopies) and challenge your experimental skills by designing and performing experiments from scratch.

Laboratory of nano-fabrication

A hands-on course introducing to the main nanofabrication techniques employed in nanoscience research and in the semiconductor industry. The presentation of top-down and bottom-up approaches will be followed by a laboratory activity with optical, electron-beam and ion-beam lithographies, and with nanocluster deposition.

Quantum physics of matter

An advanced course on matter-light and matter-electron interactions, using quantum linear response theory to discuss elementary excitations of material systems and their spectral features: electronic and phonon excitations, excitons, plasmons, polaritons.

Magnetism, spintronic and Quantum Technologies

A course devoted to quantum and statistical description of magnetic phenomena, from atomic level to collective effects, experimental techniques for magnetic characterization, and advanced applications in spintronics and molecular magnetism. The course will offer an overview on some of the emerging quantum technologies for quantum computing and quantum sensing, introducing basic concepts for the functioning of superconducting devices, on the use of spin resonance on colour centers and fundamentals of cryogenics.

Fundamental of Nanosciences

Nanosystems are both quantum worlds with astonishingly new properties and the basis of new nanodevices. The course provides a conceptual and practical framework dealing with the physics and description of a set of prototype nanosystems, from nanotubes and graphene structures to nanocrystals, quantum wells, wires and dots.

Physics of Semiconductors

Semiconductors have played a key role both in the observation of unprecedented physical phenomena and in the development of modern electronic devices. This course, suitable to students following both a curriculum with a theoretical or an experimental character, provides all the necessary ingredients to understand the fascinating physical properties of semiconductors, from their band structure description to transport phenomena, and how to exploit them in devices like transistors or to observe novel phenomena like the quantum Hall effect.

a) superconducting circuit designed to couple microwave photons to a quantum dot b) InAs nanowire wired in a three terminal configuration to work as a quantum dot at low temperature; c) current voltage characteristics showing quantized spectrum of the quantum dot. (M. Affronte)
Study plans are guided paths which are possible within a given curriculum, leading to an in-depth training in a given area of physics, as described in the Overview. The suggested choices can be tailored to the students’ scientific interests. The program coordinator and the Study plan coordinator may give further indications.

Opportunities

Attendees have access to experimental facilities (nanofabrication, low temperature laboratory, electron microscope) at the CNR NANO Institute and to the research laboratories at UNIMORE. Overall, these options make this training path at the forefront in the field and provide the necessary theoretical and experimental background to continue the carrier in any industrial environment or in the Academy, for example in PhD program in Modena or abroad. Among several ongoing collaborations, the students will have the opportunity to follow research activities carried out in other leading EU centers, including Roudbond University (NL), Forschungszentrum Jülich, Max Planck Institut (D), Polygone Scientifique (Grenoble), Karlsruhe Institut fur Technologies (D), possibly within the Erasmus Program.

Notes

Although exemplified here within an experimental Curriculum, this intrinsically interdisciplinary study plan can also be implemented with a strong theoretical content or an applied physics focus, within other curriculum of our M.Sc. program, depending on the attendee’s attitude.

Ask the Program Coordinator for guidance in choosing the appropriate study path.

Elementary particles

A course introducing the elementary constituents of matter and their interactions, as well as the role of symmetries and their violation, up to the most recent discoveries in the field (neutrino masses, Higgs boson, multi-quark states).

Quantum Information Processing

A graduate-level introduction to the theory behind quantum computers and quantum information processing (QIP) in general. Topics will range from basic QIP primitives, such as teleportation, to quantum error correction, passing through fundamental quantum computing algorithms such as Shor's factoring.

Photonics & micro-waves

A course aiming at providing knowledge and design skills-set for propagation of electromagnetic radiation in waveguides, photon sources and detectors, design of planar resonators and antennas.

Numerical algorithms for signal and image processing.

This course introduces the basic properties of Fourier transform as a tool for signal analysis, from continuous to discrete settings. Applications to signal and image filtering and compression will be presented also with some laboratory activity in the Matlab environment.

Second Year

Advanced Quantum Mechanics

A self-contained course addressing several aspects of quantum mechanics that are relevant for modern developments in several fields of physics, from condensed-matter theory to particle physics and their fundamental interactions. Emphasis will be given to the concept of Berry phases, the path integral formulation of quantum mechanics, and scattering theory.

Synchrotron radiation: basics and applications (as free choice course)

A course devoted to the working principles of synchrotrons and the use of emitted radiation, from description of single ultra-relativistic particles sources to essentials of instrumentation: storage rings, bending magnets, wigglers and undulators, free electron lasers, beam lines. Examples of ensuing popular Techniques: X-ray diffraction, scattering, absorption and X-ray microscopy. A visit to to ELETTRA labs in Trieste ends the course.

Statistical Mechanics and Phase Transitions (as free choice course)

An advanced course in classical and quantum statistical mechanics, from the theoretical foundations to phase transitions and critical phenomena, including quantum condensates (BECs, superfluids, superconductors). Attendees will be introduced to modern theoretical methods, from mean-field to statistical field theory and the renormalization group theory.