Study plan in

Quantum science & technology

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Scienze Fisiche, Informatiche e Matematiche

M.Sc. program in Physics – Curriculum Experimental nanophysics and quantum technologies

Overview

Quantum Mechanics, one the most disruptive scientific discovery of the XX century, unfolded the inner mechanisms of matter which are exploited also in engineering consumer electronics. We are now around the corner of a second quantum revolution. Quantum protocols may revolutionize every-day life, exploiting intrinsic quantum phenomena in real applications. The current challenge is to turn our present ability to manipulate single coherent quantum objects in our sophisticated laboratories into quantum technologies for everyday live. Quantum Technologies are recognized as a future key enabling technology and fostered by EU with the ten-year long QT flagpship (qt.eu). This study plan focuses both on courses on genuine quantum phenomena and courses on the technologies which allow to deploy and manipulate quantum objects for applications.

More info and suggestions from

Study plan coordinator
Prof. Marco Affronte

Program director
Prof. Paolo Bordone

Program website
`www.fim.unimore.it/LM/FIS`

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Fist year

Laboratory of nanostructures (M) – F Rossella

The course covers the entire nanotechnology chain, from raw nanomaterials (semiconductor nanowires, 2D materials, nanotubes) to device fabrication (lithography techniques) to electrical and thermal transport measurements and in manufactured nanodevices. Classical and quantum transport experiments will be discussed.

Magnetism, spintronics, and quantum technologies (M) – M Affronte

A course on quantum and statistical description of magnetic phenomena, experimental techniques for magnetic characterization, and advanced applications in spintronics and molecular magnetism. The course offers 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 color centers and fundamentals of cryogenics.

Laboratory of electron microscopy and holography (M) – M Beleggia

Modern TEMs are powerful instruments, giving access to structural and chemical information at the sub-nanometer scales. This course provides a comprehensive introduction to Transmission Electron Microscopy and to electron holography for the study of electromagnetic fields in magnetic materials and electronic devices.

Synchrotron radiation: basics and applications (M) – S D'Addato

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

Nanoscience and quantum materials (D) – E Molinari

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.

Quantum physics of matter (D) – R Magri

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.

Physics of semiconductors (D) – S D'Addato

A course providing all the necessary ingredients to understand the fascinating physical properties of semiconductors, from their electronic structure description to transport phenomena, and how to exploit them in devices like transistors, or to observe novel states of matter like the quantum Hall liquid.

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Opportunities

Attendees have access to experimental facilities (nanofabrication, low temperature labs, electron microscopes) at UNIMORE and the CNR-NANO Institute. Attendees have the opportunity to follow research activities carried out in leading partner EU centers, including Forschungszentrum Jülich (D), Max Planck Institut (D), Univ. of Glasgow (UK), Univ. of Maastricht (NL), Polygone Scientifique in Grenoble (FR), Karlsruhe Institut fur Technologies (D). Many research activities are carried out in collaboration with the National Institute for Nanosciences CNR-NANO in Modena which also contributes to teaching. **Thesis projects** are available within one of the experimental groups of the department and/or in collaborating European research groups, also within the Erasmus program or our **Double Degree program**

Employment

Overall, these options make this training at the forefront in the field, providing the theoretical and experimental background to pursue a career in any industrial environment or in the Academy, starting with a PhD, both within the Graduate School in Physics and Nanoscience in Modena and worldwide.

Notes

We encourage applications also from students with a background outside Physics - e.g., Engineering –. Candidates missing the fundamentals of modern physics in their B.Sc. studies will be guided to attend specific didactical activities to fill the gap. QTs are an intrinsically interdisciplinary field of study. A specialization in QT with a strong theoretical content or an applied physics focus can be obtained also within other curriculum. Ask the Program Coordinator for guidance in choosing the appropriate study path.

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Laser and photonics (R) – E Da Como

This course will introduce the physics of lasers and their operation principles. The taught material will cover the unique properties of laser light and some of their applications in science and technology. The second part of the course will introduce the basic components of advanced photonic devices, such as waveguides, optical fibres and the nonlinear optical phenomena therein.

Advanced spectroscopic and imaging methods (R) – R Biagi

X-ray photoemission and absorption spectroscopies are among the most used techniques to characterize properties of materials. Recent technological advances allow to achieve very high spatial (nanometer scale) and temporal (femtosecond scale) resolutions, opening the window to a new universe of phenomena.

Numerical algorithms for signal and image processing (R) – S Bonettini

A course to introduce 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

Quantum information processing (D) – P Bordone

An introduction to the theory behind quantum computers and QIP in general. Topics range from the basic concepts of QIP such as quantum entanglement and generalized quantum dynamics, to fundamental QIP algorithms, such as Shor's factoring, and quantum cryptography.

Advanced quantum mechanics (F) – M Gibertini

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

Machine learning for scientific applications (F) – F Grasselli

An introduction to key ideas and techniques in machine learning for applications in physics, from basic principles to advanced topics in supervised and unsupervised learning, including worked hands-on examples. Subjects include Gaussian Process Regression, Bayesian Inference, Kernel methods, Deep Neural Networks, Convolutional Neural Networks, and Encoder-Decoder models.

Legend: (M) mandatory course for this curriculum; (D) chosen within distinctive (*caratterizzanti*) courses; (R) chosen within related (*affini*) courses; (F) selected as a free choice course

This study plan is a suggested set of courses, chosen within the curriculum, to ensure an in-depth professional training combined with the broad spectrum of skills required to modern scientists. Mandatory, distinctive and related courses provide the natural background of this study plan. However, the study plan can also be tailored to the students' scientific interests. Ask the study plan coordinator for further indications.