UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Scienze Fisiche, Informatiche e Matematiche

M.Sc. in Physics – Laurea Magistrale Internazionale – A.Y. 2026/2027

Curriculum
Experimental Nano-physics and Quantum Technologies

The curriculum provides advanced experimental and methodological training in the study and control of **matter at the nanoscale** and in **quantum systems**. It combines solid theoretical foundations with extensive hands-on laboratory experience, preparing students to design, perform, and interpret experiments at the forefront of nanoscience and quantum technologies. The program bridges fundamental physics and emerging applications, equipping students with the skills required in both academic research and high-tech innovation environments.

A modern experimental approach to nanophysics

Four mandatory courses establish a solid grounding in quantum physics and solid-state physics, complemented by extensive laboratory work and experimental projects. Students are trained to **design and run experiments**, manage state-of-the-art **instrumentation**, and extract essential physical information from raw experimental data. Emphasis is placed on developing critical experimental judgment, enabling students to discern fundamental physical laws and phenomena while addressing real-world measurement challenges.

The curriculum introduces modern experimental techniques in **optics**, **spectroscopy**, **microscopy**, **nanofabrication**, and **low-temperature** measurements. Through direct experience with advanced instrumentation, students acquire a deep understanding of structure–property relationships in nanostructured materials, low-dimensional systems, and quantum devices, as well as the ability to devise and characterize novel experimental platforms.

Two complementary specialization tracks

The broad range of subjects and the flexible rules for elective choices support two main **specialization tracks**, while allowing students to tailor an interdisciplinary experimental profile.

The **Nanoscience and Nanodevices** track focuses on the experimental physics of nanostructures and functional materials. Students investigate the growth, fabrication, and structural, optical, and spectroscopic characterization of nanosystems such as quantum dots, nanowires, thin films, and two-dimensional materials. Particular attention is devoted to charge, spin, and energy transport phenomena at the nanoscale, with applications ranging from nanoelectronics and photonics to materials for energy and sensing technologies.

The **Quantum Technologies** track addresses the rapidly evolving field of quantum devices and information-related technologies. Students learn to control, manipulate, and detect quantum states in solid-state, photonic, and hybrid platforms. Courses cover experimental aspects of spin, charge, and superconducting qubits, quantum optics, quantum sensing, and measurement protocols. Data analysis and experiment-driven approaches to quantum control are integrated, providing a strong background for research and technology transfer in quantum science.

Opportunities and perspectives

The final thesis project is carried out in state-of-the-art experimental research laboratories, often in collaboration with **national and international facilities** such as large-scale **synchrotron radiation** research infrastructures.

Graduates are well prepared to pursue international **doctoral programs** in physics, nanoscience, and quantum engineering, as well as to enter the **job market** in research-driven and high-technology industrial sectors. Their strong experimental background, combined with expertise in advanced instrumentation and data analysis, enables them to operate effectively at the interface between fundamental research and technological innovation.

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Design your study plan in accordance with the rules specified for each group and select your preferred courses accordingly. Two free-choice courses can be selected from any curriculum or even from other degree programmes, and give you the opportunity to create a highly interdisciplinary and personalized study plan (subject to approval). For guidance, you are encouraged to contact the Programme Coordinator or your Academic Tutor.

FIRST YEAR

Title and description of the course	Hours	ECTS	SSD	Term	✓
DISTINCTIVE COURSES [B]		42			
MANDATORY COURSES					
Laboratory of nanostructures *Experimental nanotechnology is taught in a self-contained course with lectures, seminars, and hands-on experiments. Topics cover properties of semiconductor nanowires, 2D materials, nanotubes; imaging, nanolithography, and electrical/thermal transport. Students engage in frontier research at the Nanodevice Fabrication and Transport Lab, an interdisciplinary facility committed to develop innovative architectures for (bio)sensing, energy harvesting and quantum technologies.(Prof F Rossella)*	60	6	FIS/01	I II	☑
Magnetism, spintronics, and quantum technologies *The course deals with quantum and statistical description of magnetic phenomena, with a focus on experimental techniques and advanced applications in spintronics and molecular magnetism. The course also offers an overview on quantum technologies introducing basic concepts on quantum sensing with spin centers, the functioning of superconducting devices/qubits and fundamentals of cryogenics.(Prof M Affronte)*	48	6	FIS/01	I	☑
Laboratory of electron microscopy and holography *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.(Prof M Beleggia)*	48	6	FIS/01	II	☑
Synchrotron radiation: basics and applications *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.(Prof S D'Addato)*	48	6	FIS/01	I	☑
CHOOSE THREE COURSES AMONG					
Physics of semiconductors *A course providing all the necessary ingredients to understand the fascinating physical properties of semiconductors, from their electronic structure description to transport and optical phenomena, and how to exploit them in devices such as transistors, LASER, LED and solar cells, or to observe novel states of matter like the quantum Hall liquid.(Prof S D'Addato)*	48	6	FIS/03	II	☐
Fundamentals of condensed matter physics *An introductory course on the quantum theory of condensed phases of matter, focusing on the microscopic principles that govern the behavior of solids. Topics include crystal structures, lattice vibrations, electronic band theory, and transport phenomena. The course provides a solid foundation for understanding a wide range of phenomena and for pursuing further studies in advanced condensed matter physics.(Prof R Bianco)*	48	6	FIS/03	I	☐
Nanoscience and quantum materials *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.(Prof E Molinari)*	48	6	FIS/03	II	☐
Laboratory of quantum simulation of materials *Frontal lectures and hands-on tutorial sessions introduce attendees to theoretical/computational techniques for the electronic structure simulation of condensed matter systems. Special emphasis is given to Density Functional Theory, the present state-of-the-art, parameter-free and atomistic scheme for the predictive description of materials.(Prof P Bonfà)*	60	6	FIS/03	I II	☐
Elementary particles *A course on the elementary constituents of matter, their properties and their interactions, including the most recent discoveries in this field and an introduction to particle accelerators and particle detectors.(Prof A Bizzeti)*	48	6	FIS/04	I	☐
RELATED COURSES [C]		18			
CHOOSE THREE COURSES AMONG					
Advanced spectroscopic and imaging methods *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.(Prof R Biagi)*	48	6	FIS/01	II	☐
Nano-mechanics	48	6	FIS/01	I	☐

An experimental insight on the methods, procedures and apparata used in advanced research to investigate mechanical properties of materials at the nanoscale, with detailed case studies. Experiments on nano-objects are carried out in the lab, aiming at defining their intrinsic tribological properties and their macroscopic effect.(Prof A Rota)

Statistical mechanics and phase transitions	48	6	FIS/03	II	☐

An advanced course in statistical mechanics covering theoretical foundations, phase transitions, and critical phenomena. Students will explore Ginzburg-Landau theory, statistical field theory, the renormalization group approach, and selected exactly solvable models, offering a comprehensive perspective on this modern area of physics.(Prof G Goldoni)

Advanced condensed matter theory	48	6	FIS/03	II	☐

A modern course on theoretical aspects of condensed matter, in the light of current research and computational methods. Topics span from the modern theory of polarization, Wannier functions, theory of screening and plasmons, to the description of the electron-phonon interaction and the microscopic theory of superconductivity.(Prof F Grasselli)

Biological physics with laboratory	60	6	FIS/07	I II	☐

An introduction to the quantitative analysis of biological processes with the methods of physics and mathematics, together with hands-on experiences using the most advanced biophysical techniques. Students learn how to predict the behavior of some biological phenomena and how to analyze in a quantitative way experimental data.(Proff A Alessandrini, C Cecconi)

Physics education: teaching and learning physics	48	6	FIS/08	I	☐

How do people learn physics? This course explores theoretical and experimental methods from physics education research to design effective instruction. It reviews studies on conceptual challenges in classical and modern physics and evaluates teaching strategies including laboratories, digital technologies (such as AI), and active learning. Highly interactive, the course engages students with current literature and case studies, and is ideal for those interested in teaching, education research, or a research-informed view of physics.(Prof E. Tufino)

Numerical algorithms for signal and image processing	42	6	MAT/08	II	☐

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.(Prof S Bonettini)

Laboratory of machine learning and advanced computing for physics	60	6	FIS/03	I II	☐

A course covering core concepts in machine learning and high-performance computing with a physicist's approach. Foundations and applications of supervised and unsupervised learning — from Bayesian inference to deep and convolutional neural networks — are practiced with Python-based exercises. High-performance and parallel computing are introduced also for students without experience in scientific computing. Fundamental concepts and tools are implemented with MPI and OpenMP on state-of-the-art heterogeneous HPC architectures.(Proff F Grasselli, P Bonfà)

SECOND YEAR

Title and description of the course	Hours	ECTS	SSD	Term	✓
DISTINCTIVE COURSES [B]		6			

CHOOSE ONE COURSE AMONG

Advanced quantum mechanics	48	6	FIS/02	I	☐

A 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.(Prof M Gibertini)

Quantum information processing	48	6	FIS/02	I	☐

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.(Prof P Bordone)

FREE CHOICE COURSES [D]		12			

Choose at least 12 ECTSs among all courses (of any curriculum), or any other course offered at UNIMORE

PROFESSIONAL PREPARATION [F]		6			
Good practices in research		3		I	☐
Physics and society *Seminars delivered by non-academic physics professionals*		3		I	☐
Science-based innovation *Innovation-related projects at Unimore (see e.g. clab.unimore.it)*		6			☐
High-performance computing in sciences HPC courses (see e.g. eventi.cineca.it)					☐
THESIS PROJECT AND DISSERTATION [E]		36			