Study plan in

Applied physics

UNIMORE
Università degli Studi di Modena e Reggio Emilia

Dipartimento di Scienze Fisiche, Informatiche e Matematiche

M.Sc. program in Physics – Curriculum Biophysics and applied physics

Overview

This study plan features a choice of specialized and modern courses with a broad spectrum of competences, all which are highly desirable the present transition to data-driven technologies. Specific to this study plan is a unique combination of courses in **data-science** and courses in the **physics of matter**, including modern quantum descriptions of solids, which underlying **enabling technolgies**, such as nano-technology and quantum technologies, which may drive radical changes in economic and societal areas. Our courses cover the practical manipulation of condensed matter and device **deplo yment** at the **nanoscale**, its characterization and conceptualization, as well as **numerical technicques** which allow for optimization processes of material properties and device performance.

Goal

The goal of this study plan is to provide a solid background to those students interested in applied sectors – from nanotechnology, to quantum systems and machine learning - also beyond academy. Here, all courses are designed to provide basic understanding of the physical phenomena in the field of (nano)material science and solid-state physics, as well as technical applications in dedicated laboratories. Students following this study plan will be capable to design, plan and execute **materials investigation**, **data and signal processing**, system programming and **automated learning methods**.

More info and suggestions from

Study plan coordinator
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Program director
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Program website
`www.fim.unimore.it/LM/FIS`

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Fist year

Laboratory of nanostructures **(D)** – 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 **(D)** – 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.

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.

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.

Laboratory of Quantum Simulation of Materials **(D)** – A Ruini

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.

Machine learning for scientific applications **(D)** – 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.

Nano-mechanics **(R)** – A Rota

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.

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Fields of specialization

- Methods of Materials and Nanostructures Analysis
- Devices Physics
- Data Acquisition and Systems Architecture
- Data-science and Machine Learning

Opportunities

Thesis projects are proposed by renowned scientists participating in a large network of collaborations, which also include EU companies. Experimental thesis projects will be conducted in modern laboratories featuring advanced nano-tehcnology and spectroscopic capabilities, also at partner centers or at the Elettra Synchrotron facility. Computational courses and thesis projects exploit the most powerful architectures, either at the Unimore HPC facility or at CINECA, a Tier-0 center of HPC-Europe. Students interested in technology transfer are encouraged to apply for the CBI multi-disciplinary projects proposed by the Comtamination Lab of Unimore.

Employment

The broad range of expertises learnt within study plan allows to apply for doctoral studies in Applied Physics, Nanotechnology or Biotechnology, at the **Graduate School in Physics and Nanoscience** in Modena or worldwide. Many opportunities are envisioned in all high-tech companies, especially within R& D units, thanks to the combination of deep understanding and practical experiences in materials analysis, learning methods and data predictions.

Notes

Courses from Engineering or other applied science programs may enlarge the scope of training. Student specifically interested in clinical applications may choose the Medical physics course. We also provide an innovative course in Educational physics for students who foresee a possible career in high-school teaching. Ask the Study plan coordinator for further indications.

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High Performance Computing for physical sciences **(R)** – P Bonfà

A course which combines lectures and hands-on projects to exploit modern computers in diverse fields, from high-throughput material screening to climate modeling to black holes formation, introducing to general concepts of parallel computing and practical approaches based on OpenMP, MPI, and GPU programming.

Computational and statistical learning **(R)** – M Prato, G Franchini

An introduction to the mathematical models and the numerical algorithms at the basis of the machine learning field, starting from Vapnik's general formulation and crossing the main supervised and unsupervised strategies. The course syllabus includes the Vapnik-Chevonenkis theory, linear and kernel methods for classification and regression, ensemble methods, unsupervised and deep learning techniques, all accompanied by laboratory experiences and implementation details.

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

Advanced quantum mechanics **(D)** – 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.

Laboratory of electron microscopy and holography **(F)** – 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 **(F)** – 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.

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.