ANNEX 1

DEGREE PROGRAM DIDACTIC REGULATIONS

QUANTUM SCIENCE AND ENGINEERING

CLASSE LM-44/LM-120 (c.u.)

School: : Politecnica e delle Scienze di Base

Department: Fisica "Ettore Pancini"

Didactic Regulations in force since the academic year 2024-2025

STUDY PLAN

KEY

Type of Educational Activity (TAF):

B = Characterising

C = Related or Supplementary

D = At the student's choice

E = Final examination and language knowledge

F = Further training activities

Year 1									
Title Course	**SSD**	**Module**	**CREDITS**	**Hours**	**Type Activities** *(lectures, workshops, etc.)*	**Course Modalities** *(in-person, by distance)*	**TAF**	**Disciplinary area**	**Mandatory/ optional**

Foundations of Quantum Mechanics	FIS/02	Mod I Principles	12	48	Frontal lesson	In-person	B	Discipline matematiche ,fisiche e informatiche	Mandatory
Foundations of Quantum Mechanics	FIS/03	Mod II Physical systems		48		In-person	B		
Microwave circuits and technologies	ING-INF/02	single	6	48	Frontal lesson	In-person	B	Discipline ingegneristiche	Mandatory
Digital Electronics for Quantum Applications	ING-INF/01	single	6	48	Frontal lesson	In-person	B	Discipline ingegneristiche	Mandatory
Principles of Quantum Communications	ING-INF/03	single	6	48	Frontal lesson	In-person	C	Attività affini e integrative	Mandatory
Quantum Computation:	INF/01	Mod I: Theory	12	48	Frontal lesson	In-person	B	Discipline matematiche ,fisiche e informatiche	Mandatory
Quantum Computation:	ING-INF/05	Mod II:: Architectures and High Performance		48		In-person		Discipline ingegneristiche	
Applied Quantum Systems	FIS/03	single	9	72	Frontal lesson	In-person	B	Discipline matematiche, fisiche e informatiche	Mandatory
Mandatory (one of your choices)		single	6	48	Frontal lesson	In-person	C		Mandatory (one of your choices)

Year 2

Title Course	**SSD**	**Module**	**CREDITS**	**Hours**	**Type Activities** *(lectures, workshops, etc.)*	**Course Modalities** *(in-person, by distance)*	**TAF**	**Disciplinary area**	**Mandatory/ optional**
Quantum circuit electrodynamics and Quantum devices	ING-IND/31	single	9	72	Frontal lesson	In-person	B	Discipline ingegneristiche	Mandatory
Physical principles of quantum information	FIS/03	single	6+ 6	48	Frontal lesson	In-person	C	Attività affini e integrative	Mandatory (two of your choices) or see note 1
Quantum optics	FIS/03	single		48		In-person			
Quantum Simulators	FIS/03	single		48		In-person			
Quantum materials and solid-state qubits	FIS/03	single		48		In-person			
Advanced Programming	ING-INF/05	single		48		In-person			
Software quantistico	INF/01	single		48		In-person			
Quantum metrology and sensors	ING-INF/07	single		48		In-person			
Advanced Quantum Communication Networks	ING-INF/03	single		48		In-person			
Quantum Detectors for Fundamental Science	FIS/01	single		48		In-person			

Superconducting Quantum Technologies	FIS/03	single		48		In-person			
Quantum Chemistry	CHIM/02	single		48		In-person			
Quantum Measurement Theory	FIS/02	single		48		In-person			
Quantum Algoritms	FIS/02	single		48		In-person			
Nanoscale Processing and Characterization for Advanced Devices	FIS/01	single		48		In-person			
Nonlinear Systems	ING-INF/04	single		48		In-person			
Quantum detectors for applied science	FIS/07	single		48		In-person			
Mathematics for Quantum Mechanics	MAT/07	single		48		In-person			
Mathematical Methods for Quantum Information	MAT/05	single		48		In-person			
One of your choices or see note 2			12	96	Frontal lesson or internship		D	your choices	Mandatory (one of your choices) or see note 2
One of your choices or see note 2		single	6	48	Laboratory or internship		F	your choices	Mandatory (one internship)
One of your choices or see note 3			3	24			F	your choices	

Final test			21	168			E	Final test	Mandatory

Note 1: In addition to the courses listed in Table A, students may also include in this space any courses available for the following Master's degree programs: Physics, Computer Science, Electronic Engineering, Telecommunications Engineering, and Computer Engineering.

Note 2: Students may choose any course offered by the University. Additionally, internship activities may be incorporated into the curriculum, subject to prior approval.

Note 3: These credits can be strategically utilized by students seeking to broaden their language proficiency, enhance their computer and digital skills, participate in training and orientation internships, or acquire additional competencies conducive to professional integration. Specifically, these credits may be allocated to preparatory training activities related to the final assessment.

Beyond the standard academic pathway outlined above for those with Bachelor's degrees, expedited, streamlined tracks are also available for individuals who have already completed Master's degrees in Physics or Engineering. These accelerated routes are designed to facilitate the completion of the Master's degree in Quantum Science and Engineering within one year, equating to 60 credits. The specifics of these abbreviated tracks will be delineated by the Educational Coordination Committee, taking into account the student's previous Master's degree and their academic history.

ANNEX 2.1

DEGREE PROGRAM DIDACTIC REGULATIONS

QUANTUM SCIENCE AND ENGINEERING

CLASSE LM-44/LM-120 (c.u.)

School: : Politecnica e delle Scienze di Base

Department: Fisica “Ettore Pancini”

Didactic Regulations in force since the academic year 2024-2025

Course: Digital Electronics for Quantum Applications	**Teaching Language:** English	
SSD (Subject Areas): Ing-INF/01		**CREDITS:** 6
Course year: II	**Type of Educational Activity: C**	
Teaching Methods: In person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The activities of interest include: theoretical and experimental studies of physical principles and technologies; design and implementation of devices, circuits, apparatus, and systems based on specifications, regulations, and costs set by applications. The field encompasses a wide range of skills (semiconductor devices for low and high frequency, circuits, microcircuits, sensors, electronic instrumentation, nanotechnologies, nanoelectronic devices and circuits, photonic devices, energy efficiency of circuits and systems, computer tools for assisted design, etc.), each comprising methodological, design, technological, and experimental aspects.		
Objectives: Provide students with the fundamental concepts for the analysis of basic integrated analog electronic circuits for quantum applications. To this end, the characteristics of fundamental electronic devices are introduced: diodes and MOS transistors, and their applications are studied in elementary amplifiers, with specific reference to integrated analog circuits for qubits in semiconductor technology.		
Propaedeuticities: none **Is a propaedeuticity for:**		
Types of examinations and other tests: oral		

Course: Advanced Programming		**Teaching Language:** English
SSD (Subject Areas): ING-INF/05		**CREDITS:** 6
Course year: II	**Type of Educational Activity:** B	
Teaching Methods: in-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector is characterized by the set of scientific fields and scientific-disciplinary competences related to the design and realization of information processing systems, as well as their management and utilization in various application contexts with methodologies and techniques typical of engineering. This includes theoretical foundations, methods, and technologies aimed at producing technically valid projects, from both the adequacy of the proposed solutions and the feasibility of technical implementation, to economic feasibility and organizational effectiveness. These foundations, methods, and technologies cover all aspects related to a processing system, from hardware to software.		
Objectives: The course aims at providing students with advanced knowledge and expertise related to concurrent and distributed programming, introducing the tools to develop and debug multithreading and network applications using Python, and introducing the concept of middleware and of the different solutions used in industry, focusing on both the message-oriented and service-oriented models, with application on real technology.		
Propaedeuticities: none **Is a propaedeuticity for:** none		
Types of examinations and other tests: oral examination with project discussion		

Course: Applied Quantum Systems	**Teaching Language:** English
SSD (Subject Areas): FIS/03	**CREDITS:** 9
Course year: II	**Type of Educational Activity:** B
Teaching Methods: In-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Theoretical and experimental treatment of quantum electronics and quantum information. material science from metals to semiconductors and strongly correlated systems, superconductors, mesoscopic and nanoscale systems to build quantum machines.	
Objectives: This course aims at illustrating "quantum mechanics at work", not only as a key to interpret nature but also as a drive to build new "machines" It will be shown how to implement quantum machines on the basis of quantum effects. Ability to understand quantum platforms and the underlying physical concepts. This course will cover a breadth of archetypal systems for quantum technologies with a special focus on solid state systems: nuclear magnetic resonance, laser amplifiers and self-sustained oscillators, pulse sequence techniques, Ramsey spectroscopy, meso-scale low-dimensional devices, quantum Hall effect, quantum confinement, conductance quantization, magneto oscillation, macroscale quantum effect devices and circuits such as Cooper-pair boxes and superconducting quantum circuits. The course will also deal with materials challenges which provide opportunities for quantum computing hardware.	
Propaedeuticities: Foundations of Quantum Mechanics **Is a propaedeuticity for:**	
Types of examinations and other tests: oral	

Course: Advanced Quantum Communication Networks	**Teaching Language:** English
SSD (Subject Areas): ING-INF/03	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: The course is organized by integrating traditional lectures with interactive laboratory sessions. Furthermore, seminars will be eventually organized during the course by inviting experts in the relevant fields, and innovative teaching methods, as for example flipped classroom and feedback teaching strategies, will be adopted.	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector studies the planning, design, construction (hardware and software) and operation of equipment, systems and infrastructures for applications aimed at: the transfer of signals via cable (copper or fibre), via radio (terrestrial or satellite) or other means of propagation, with the use of specific technologies such as optical and mobile communications; (omissis) to network interconnection for the transport of information (omissis). Basic aspects are included (theory of random phenomena, information, codes, signals, traffic, protocols, etc.) (omitted).	
Objectives: The aim of the course is to provide the students with the knowledge related to the analysis and design of communication protocols for quantum networks. First, the fundamentals of classical communication networks will be introduced. Then, the advanced notions related to the design of quantum networks, including the issues arising with the distribution of entanglement among remote nodes, are presented. Furthermore, the Quantum Internet protocol stack will be carefully presented and analyzed. To this aim, its unconventional requirements and peculiarities with respect to the classical TCP/IP protocol stack will be properly discussed. Some use cases, such as distributed quantum computing and quantum placement of quantum links, will be presented and analyzed.	
Propaedeuticities: Principles of Quantum Communications **Is a propaedeuticity for:** None	
Types of examinations and other tests: Oral and project discussion	

Course: Foundations of Quantum Mechanics Mod I: Principles	**Teaching Language:** English
SSD (Subject Areas): Fisica Teorica, Modelli e Metodi Matematici (FIS02)	**CREDITS:** 6
Course year: 1	**Type of Educational Activity:** B
Teaching Methods: in person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Knowledge and competences necessary for the theoretical treatment of quantum phenomena, starting from foundational laws and principles together with the necessary mathematical tools. It includes the competences needed for understanding the mathematics and the modelling of quantum physics at a deeper level.	
Objectives: Basic ideas and mathematics of Quantum Mechanics. This course will cover the fundamentals of quantum physics in its phenomenological, theoretical and experimental basis. The course is aimed at conveying working knowledge of the principles of quantum mechanics towards the understanding of quantum information processing and quantum computation.	
Propaedeuticities: none **Is a propaedeuticity for:** All the courses from the second semester of first year onwards.	
Types of examinations and other tests: Written and oral	

Course: Foundations of Quantum Mechanics (FQM) - Mod II: Physical systems	**Teaching Language:** English	
SSD (Subject Areas): FIS/03		**CREDITS:** 6
Course year: I (Semester I)	**Type of Educational Activity:** B	
Teaching Methods: In-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: "theoretical and experimental treatment of the states of both atomic and molecular aggregates...treatment of the propagation properties and interaction of photons with fields and matter"		
Objectives: Knowledge of the principles of quantum mechanics towards the understanding of physical realizations of quantum computers.		
Propaedeuticities: Foundations of Quantum Mechanics Mod I: PRINCIPLES **Is a propaedeuticity for:** Quantum Computation, Applied Quantum Systems, Quantum circuit electrodynamics and Quantum devices		
Types of examinations and other tests: Oral		

Course: Mathematics for Quantum Mechanics		**Teaching Language:** English
SSD (Subject Areas): MAT/07		**CREDITS:** 6
Course year: first or second	**Type of Educational Activity:** affine and integrative (C)	
Teaching Methods: in-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Aspects of mathematical physics and theory of dynamical systems applied to quantum mechanics, with both analytical and geometric techniques.		
Objectives: Working knowledge of mathematical tools and methods that find application in the field of quantum mechanics, such as partial differential equations, eigenvalue problems, developments in orthogonal functions, operator theory.		
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:** none		
Types of examinations and other tests: written and oral exam		

Course: Mathematical Methods for Quantum Information	**Teaching Language:** English	
SSD (Subject Areas): MAT/05		**CREDITS:** 6
Course year: first or second	**Type of Educational Activity:** affine and integrative (C)	
Teaching Methods: in-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Calculus of variations and theory of functions, both real and complex, analytical number theory, applied to quantum information.		
Objectives: Working knowledge of mathematical tools and methods that find application in the field of quantum information, such as aspects of complex number theory, linear algebra in Hilbert spaces, operator theory, eigenvalue problems, probability theory, elements of number theory.		
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:** none		
Types of examinations and other tests: written and oral exam		

Course: Microwave circuits and technologies	**Teaching Language:** English
SSD (Subject Areas): ING-INF/02	**CREDITS:** 6
Course year: I	**Type of Educational Activity: B**
Teaching Methods: in-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The design of high frequency passive circuits has been developed in parallel, analysing scenario of increasing difficulties, with a variety of elements, including active ones: this is the area of microwave and millimeter wave components and circuits. ING-INF/02 Electromagnetic Fields. The sector has its historical origins from the study of electromagnetic waves by means of Maxwell's equations. This model, still very modern, offers continuous opportunities for deductive analysis and formal ideas, constituting a broad basis of work for scholars of electromagnetic fields. Initial developments were aimed at telecommunications; this is where studies on free and guided propagation and on antenna design methods originate, the true cornerstones of the sector, together with the analysis of scattering problems. The most recent developments in propagation studies have been directed towards the characterization of the channel for mobile communications and towards optical components and systems. The design of very high frequency passive circuits has been developed in parallel, analysing scenario of increasing difficulties, with a variety of elements, including active ones: this is the area of microwave and millimeter wave components and circuits. More recently, the sectors of remote sensing, fundamental for environmental diagnostics, in particular through modern radars, and that of the biological effects of electromagnetic fields, fundamental to check that the radio systems do not constitute harm to human beings and to identify medical applications, have been developed. Furthermore, the investigation on electromagnetic compatibility problems has been extended, together with industrial applications for the treatment of materials and the creation of sensors.	
Objectives: The course is aimed at providing the skills and methodological and operative tools necessary to concretely apply, in the field of quantum technologies, the operatvie principles of circuits and devices working at Microwaves and Radio Frequency, and the theoretical-numerical analysis techniques and synthesis and design techniques. In order to complete the training, the theoretical-numerical lessons will be accompanied by laboratory experiences and design sessions in which the student will be asked to use, also with the aid of the most recent calculation software, the skills acquired during the course to design and characterize specific components and circuits used in quantum systems.	
Propaedeuticities: **Is a propaedeuticity for:**	
Types of examinations and other tests: Oral	

Course: Nanoscale Processing and Characterization for Advanced Devices	**Teaching Language:** English
SSD (Subject Areas): FIS/03 – Physic of Matter	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: Live lectures on theory for 70% of frontal time and measurements in lab for 30% of rest time.	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Skills and methods necessary for the low-noise fabrication and measurement at cryogenic temperatures of nanoscale devices. Skills necessary for the treatment of experimental techniques used in clean room environments as well as the theory of electronic transport in the classical and quantum limits of junctions and devices at the nanoscale. Cryogenic techniques and DC and RF measurement schemes for low-noise characterization of superconducting devices. Nanofabrication protocols for the creation of superconducting nanowires and applications in the field of quantum communication.	
Objectives: Experimental methods used in clean room environments, classical and quantum transport theory of junctions and devices, low temperature cryostats, DC and RF low noise measurement, realization of superconducting nanowires, properties and applications in quantum computation.	
Propaedeuticities: None **Is a propaedeuticity for:**	
Types of examinations and other tests: oral and project discussion	

Course: Physical principles of quantum information		**Teaching Language:** English
SSD (Subject Areas): FIS/03		**CREDITS:** 6
Course year: first or second	**Type of Educational Activity:** C	
Teaching Methods: in-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Theoretical and experimental treatment of atomic and molecular physics, materials science and related technology from the nanoscopic to the macroscopic level, as well as photonics, optics, optoelectronics, quantum electronics and quantum information.		
Objectives: Learning of the principles of quantum information physics. Qubits, entanglement, Bell inequalities, no-cloning theorem, measurement theory, coherence and decoherence; the concepts of fidelity and quantum state reconstruction (with experimental aspects); quantum information with discrete and continuous variables, with examples of physical implementations using different platforms (atoms, ions, superconducting circuits, photonics); simple quantum protocols (quantum cryptography and teleportation); intrinsic and technological limits of quantum information. Quantum information compression, efficient quantum algorithms and quantum complexity.		
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:** none		
Types of examinations and other tests: written and oral exam		

Course: Quantum optics		**Teaching Language:** English
SSD (Subject Areas): FIS/03		**CREDITS:** 6
Course year: first or second	**Type of Educational Activity:** C	
Teaching Methods: **in-person**		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Theoretical and experimental treatment of atomic and molecular physics, as well as photonics, optics, optoelectronics, quantum electronics and quantum information.		
Objectives: Learning of the fundamental concepts of the quantum theory of electromagnetic radiation, with insights into: Fock states, coherent states, "squeezed" states; field-field and photon-photon interference; elements of quantum information using photons; experimental methods of quantum optics.		
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:** none		
Types of examinations and other tests: written and oral exam		

Course: Quantum Detectors for Fundamental Science	**Teaching Language:** English
SSD (Subject Areas): FIS-03 Physics of Matter	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: IN-PERSON	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The training objectives of the course aim to develop both theoretical and experimental aspects concerning with the interaction of photons with matter, their detection with ultralow sensitive detection schemes, and more generally aspect of integrated, opto-electronics and quantum electronics for understanding the quantum detectors in fundamental science experiments. In particular: Theory of quantum noise. Fundamentals of Single-Photon Detectors (i.e. AVP, SMP, SNSPDs, PCC). Superconducting qubit-based detectors. Quantum sensing devices including magnetometers and interferometers, Applications of quantum detectors to fundamental science experiments.	
Objectives: The course is aimed at providing the fundamental aspects of quantum detectors including single photon detectors, superconducting qubit-based sensors, and quantum sensing devices. The use of such detectors in fundamental science experiments will be presented and discussed. The student will be able to perform single photon measurements on superconducting devices, and to perform basic measurements on superconducting quantum bits for evidencing basic properties in the detection context. The contents will develop the ability to explain and use the principles of quantum theory of electromagnetic radiation within the main experimental methods presented within the course. Moreover, they will develop the capability of sketch and explain the schematic layout of investigated quantum detectors and the configurations of the experiments where they are proposed or used.	
Propaedeuticities: Foundations of Quantum Mechanics **Is a propaedeuticity for:** none	
Types of examinations and other tests: A combination of an oral test (80%) and discussion on an assigned project (20%) inspired by the current literature	

Course: Principles of Quantum Communications	**Teaching Language:** English
SSD (Subject Areas): ING-INF/03	**CREDITS:** 6
Course year: second	**Type of Educational Activity:** C

Teaching Methods: The course is organized by integrating traditional lectures with interactive laboratory sessions based for example on the IBM Q-Experience platform. Furthermore, seminars will be eventually organized during the course by inviting experts in the relevant fields, and innovative teaching methods, such as flipped classroom and feedback teaching strategies, will be adopted.

Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector studies the planning, design, construction (hardware and software) and operation of equipment, systems and infrastructures for applications aimed at: the transfer of signals via cable (copper or fibre), via radio (terrestrial or satellite) or other means of propagation, with the use of specific technologies such as optical and mobile communications; (omissis) to network interconnection for the transport of information (omissis). Basic aspects are included (theory of random phenomena, information, codes, signals, traffic, protocols, etc.) (omitted).

Objectives: The aim of the course is to provide the students with the principles of quantum information theory and their application to quantum communications. First, the fundamentals of classical communications will be introduced. Then, the notion of quantum bit (qubit), together with the principles and the unconventional peculiarities of quantum information processing, are presented. Stemming from these preliminaries, the course will provide the students with the advanced notions related to quantum communications, namely, to the issues of transmitting classical/quantum information through quantum channels. To this aim, the quantum noise and its peculiarities with respect to classical noise will be properly introduced. Subsequently, secure communications will be discussed by analyzing Quantum Key Distribution (QKD) techniques (including BB84 and Ekert-91) and their practical realization. Furthermore, genuine entangled-based quantum communication techniques (including superdense coding and quantum teleportation) will be properly introduced and analyzed, by also discussing the strategies (e.g., quantum error correction) for counteracting the noise effects. Finally, the challenges arising with the design of quantum communications will be discussed in the light of an integration within the lowest layers of the Quantum Internet protocol stack, by also briefly introducing its unconventional requirements and differences with respect to the standard-de-facto TCP/IP protocol stack. The students will have the opportunity to perform simple experiments on a real quantum computer via for example the IBM Q- Experience platform.

Propaedeuticities: None

Is a propaedeuticity for: Advanced Quantum Communication Networks

Types of examinations and other tests: Oral and project discussion

Insegnamento: Quantum Algoritms		**Lingua di erogazione dell'Insegnamento:** English
SSD: Fisica Teorica, Modelli e Metodi Matematici (FIS02)		**CFU:** 6
Anno di corso: II	**Tipologia di Attività Formativa:** C	
Modalità di svolgimento: In presence		
Contenuti estratti dalla declaratoria del SSD coerenti con gli obiettivi formativi del corso: Knowledge and competences necessary for the theoretical treatment of quantum phenomena, starting from foundational laws and principles together with the necessary mathematical tools. It includes the competences needed for understanding the mathematics and the modelling of quantum physics at a deeper level.		
Obiettivi formativi: This course covers the fundamental notions of quantum computation and quantum algorithms. The course will introduce the general concepts and methods of quantum computation and will focus on the necessary tools. It will also include a survey of the known most notable quantum algorithms with their features and challenges. The course will also contain topics from quantum communication, cryptography, and quantum error correction.		
Propedeuticità in ingresso: Foundations of Quantum Mechanics **Propedeuticità in uscita:**		
Tipologia degli esami e delle altre prove di verifica del profitto: scritto e orale		

Course: Quantum Chemistry	**Teaching Language:** English
SSD (Subject Areas): CHIM/02	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: In person Live lectures on theory for 80% of frontal time, exercises for 20% of frontal time.	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Intro to Quantum Mechanics: the postulates that form the basis of quantum theory. The time-independent Schrödinger equation in one, two, and three dimensions. The hydrogen atom. Approximation methods and computational approaches for quantum chemistry: perturbation theory, nonlinear and linear variational method. Many-electron atoms: antisymmetry principle and Slater determinants; classification of atomic states; spin-orbit interaction. Molecules and the chemical bond: the Born-Oppenheimer approximation, the hydrogen molecule; homonuclear and heteronuclear diatomic molecules. Polyatomic molecules and molecular orbital theory. Use of group theory for the symmetry classification of molecular orbitals. Nuclear motion. Molecular spectroscopy: rotational, vibrational and electronic. Chemical reactions. The interaction of atoms and molecules with light.	
Objectives: Acquisition of basic knowledge of the physical theories, the approximations and some computational strategies that are involved in the quantum-mechanical description of atomic and molecular systems. Expertise in evaluation of the appropriateness of a quantum-chemical model for the description of molecular / chemical systems.	
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:**	
Types of examinations and other tests: Written and oral	

Course: Quantum circuit electrodynamics and Quantum devices	**Teaching Language:** English
SSD (Subject Areas): ING-IND/31	**CREDITS:** 9
Course year: II	**Type of Educational Activity:** Engineering Disciplines, B
Teaching Methods: In-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The field studies the theoretical and experimental aspects of the two complementary strands of electromagnetic fields and circuits and the development of their applications in various engineering sectors. In the first strand, electromagnetic field problems are studied... In the second strand, electrical and electronic circuits are studied..., as well as their models: linear, non-linear, and time-variant, with lumped and distributed parameters... The two complementary approaches are applied to the analysis, synthesis, physical and numerical modeling, and automatic design of equipment, devices..., to superconductivity, electromagnetic compatibility, and more.	
Objectives: In this course, students will first build a strong theoretical foundation, based on the classical Lagrangian and Hamiltonian formulations and their quantum counterparts, which is essential for understanding the quantum behavior of electrical circuits. This background will then serve as a basis for exploring superconducting qubits, where students will delve into the operational mechanisms of these qubits, including the role of Josephson junctions, and learn to differentiate between various qubit types such as charge, flux, phase, and Transmon. As the course progresses, the focus will shift to the dynamics of dissipative quantum circuits. Students will investigate how quantum fluctuations and environmental interactions contribute to decoherence processes, and study mechanisms of decay and dephasing that affect qubit stability and performance. A significant portion of the course will be dedicated to practical skills in qubit-cavity coupling and quantum control. Students will become adept at techniques for both resonant and dispersive couplings, which are critical for controlling qubits within cavities and crucial for accurate qubit readout. Finally, the course will explore the quantum state engineering and the practical implementation of quantum gates and algorithms. Attention will be given to scalability challenges, aiming to equip students with the understanding necessary to contribute to the advancement of scalable quantum computing technologies and error correction methods that underpin robust quantum information processing.	
Propaedeuticities: Foundations of Quantum Mechanics, Microwave Circuits and Technologies **Is a propaedeuticity for:**	
Types of examinations and other tests: oral	

Course: Quantum Computation - Mod I: Theory	**Teaching Language:** English
SSD (Subject Areas): INF/01	**CREDITS:** 6
Course year: I	**Type of Educational Activity:** B
Teaching Methods: In-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The scientific field is concerned with scientific and educational-educational activity in the fields of computer research and information theory, placed at the basis of the computer approach to the study of problems and, jointly, the design, implementation, and use of computer systems for innovation in society. Special attention is paid to the method, based on modeling, formalization, and experimental verification. Therefore, the field includes, alongside all basic and general aspects, algorithmic (algorithm design and analysis, computability and complexity, information theory, codes, and cryptography), logical, semantic, and methodological foundations of computer science, including classical and quantum computational models.	
Objectives: By the end of the course, students will develop: • A solid understanding of the fundamental concepts of quantum computing, with a focus on computational architectures, algorithms, and development tools. • Ability to design algorithms based on the quantum computing paradigm. • Problem solving skills to interpret a problem, develop a strategy to solve it, and model this strategy through an appropriate quantum algorithm. • A high level of understanding of the relationships existing between two significant areas of computer science, quantum computing and artificial intelligence.	
Propaedeuticities: Foundations of Quantum Mechanics **Is a propaedeuticity for:** None	
Types of examinations and other tests: Oral examination with project discussion.	

Course: Quantum Computation: Mod II: Architectures and High Performance	**Teaching Language:** English
SSD (Subject Areas): ING-INF/05	**CREDITS:** 6
Course year: I	**Type of Educational Activity:** B
Teaching Methods: in-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector is characterized by the set of scientific fields and scientific-disciplinary competences related to the design and realization of information processing systems, as well as their management and utilization in various application contexts with methodologies and techniques typical of engineering. This includes theoretical foundations, methods, and technologies aimed at producing technically valid projects, from both the adequacy of the proposed solutions and the feasibility of technical implementation, to economic feasibility and organizational effectiveness. These foundations, methods, and technologies cover all aspects related to a processing system, from hardware to software.	
Objectives: The course provides the definition of the internal mechanisms of information processing systems. The course will cover topic related to the definition of a computer system, its architecture, its operating modes and basic techniques for designing a digital circuit, the architecture of operating systems and concurrent and system programming. The course also covers the fundamentals of parallel architectures for high performance applications.	
Propaedeuticities: none **Is a propaedeuticity for:** none	
Types of examinations and other tests: oral examination with project discussion	

Course: Quantum materials and solid-state qubits	**Teaching Language:** English
SSD (Subject Areas): FIS/03	**CREDITS:** 6
Course year: 2	**Type of Educational Activity:** C
Teaching Methods: In-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The contents concern theoretical and computational research in the fields of solid state physics and materials science and related technology from the nanoscopic to the macroscopic level, quantum electronics and quantum information, as well as the statistical properties of matter and complex systems. The contents also concern issues related to the foundations of quantum physics.	
Objectives: The aim of the course is to introduce students to modern concepts il solid state physics necessary for understanding the basic elements related to the implementation of the hardware of a solid state quantum computer. The program of the course focuses on superconductor and semiconductor implementations. In both cases, it will be discussed the ideal operating scheme together with the most important challenges related to the control and reduction of noise and imperfections.	
Propaedeuticities: None **Is a propaedeuticity for:** None	
Types of examinations and other tests: Oral exam	

Course: Quantum metrology and sensors	**Teaching Language:** English
SSD (Subject Areas): ING-INF/07 – Electrical and Electronic Measurements	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods:in-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector's own methodologies concern the modeling and metrological characterization of measurement methods, components and systems, the extraction, interpretation, and representation of measurement information. Research topics include the design, implementation and characterization of measurement methods, components, and systems, with particular attention to improving the metrological performance obtained.	
Objectives: Providing students with specialized knowledge aimed at designing, implementing and characterizing methods, procedures and devices typical of electrical and electronic measurement engineering when applied to solutions and systems based on quantum technologies or when enhanced through the use of quantum technologies.	
Propaedeuticities: Foundations of Quantum Mechanics **Is a propaedeuticity for:**	
Types of examinations and other tests: Oral exam and discussion of a practical exercise	

Course: Quantum Simulators	**Teaching Language:** English
SSD (Subject Areas): FIS/03	**CREDITS:** 6
Course year: first or second	**Type of Educational Activity:** C
Teaching Methods: in-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Theoretical and experimental treatment of atomic and molecular physics, materials science and related technology from the nanoscopic to the macroscopic level, as well as photonics, optics, optoelectronics, quantum electronics and quantum information.	
Objectives: Learning the key concepts and main experimental methodologies of quantum simulation of strongly correlated many-body systems and their implementation with cold atoms, quantum dot systems, ions, superconducting circuits and photons.	
Propaedeuticities: Foundations of quantum mechanics **Is a propaedeuticity for:** none	
Types of examinations and other tests: written and oral exam	

Course: Quantum detectors for applied science	**Teaching Language:** English	
SSD (Subject Areas): FIS/07		**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C	
Teaching Methods: In person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The Course matches the contents of the declaratory of SSD FIS/07 as regards the study and the development of experimental physical methods in environmental, biological and medical fields, as well as the development and the utilization of instrumentation to control and detection of physical phenomena in the fields of environmental monitoring and bioremediation, diagnostics and therapy, and the physical techniques for biomedical diagnostics.		
Objectives: The Course will provide the students with advanced scientific contents, and related technical knowledge, on quantum radiation detectors, specifically on photon detectors, in various application fields of physics, particularly for medical and biosensors applications. The Course will also provide technical skills for the understanding and the practical use of quantum radiation sensors, through laboratory sessions in the applied biomedical field. All knowledge, capacity and ability so acquired could be applied also for research in experimental physics and applications to R&D in several fields of physics and engineering.		
Propaedeuticities: None **Is a propaedeuticity for:** None		
Types of examinations and other tests: Oral exam with discussion of a written report of the laboratory activity.		

Course: Quantum Software	**Teaching Language:** English
SSD (Subject Areas): INF/01	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: In-person	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The scientific field is concerned with scientific and educational-educational activity in the fields of computer research and information theory, placed at the basis of the computer approach to the study of problems and, jointly, the design, implementation, and use of computer systems for innovation in society. Special attention is paid to the method, based on modeling, formalization, and experimental verification. Therefore, the field includes, alongside all basic and general aspects, algorithmic (algorithm design and analysis, computability and complexity, information theory, codes, and cryptography), logical, semantic, and methodological foundations of computer science, including classical and quantum computational models; the skills needed to model and design languages (environments and methodologies for programming, software engineering).	
Objectives: By the end of the course, students will develop: • A solid understanding of the major quantum programming frameworks and languages (Qiskit, PennyLane, Cirq...). • Ability to implement and engineer applications based on quantum computing and hybrid classical/quantum approaches. • Ability to integrate quantum computing-based software into frameworks for optimization and artificial intelligence.	
Propaedeuticities: Quantum Computation **Is a propaedeuticity for:** None	
Types of examinations and other tests: Oral examination with project discussion.	

Course: Quantum Measurement Theory	**Teaching Language:** English	
SSD (Subject Areas): FIS02		**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C	
Teaching Methods: In person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: Knowledge and competences necessary for the theoretical treatment of quantum phenomena, starting from foundational laws and principles together with the necessary mathematical tools. It includes the competences needed for understanding the mathematics and the modelling of quantum physics at a deeper level.		
Objectives: The main aim of the course is to provide the student with some concepts and tools of quantum measurement theory that are fundamental for a deeper understanding of quantum mechanics and quantum information, and of the sharp differences – but also of the analogies – between classical and quantum theory. The course is also aimed at introducing the student to the theory of open quantum system and quantum decoherence.		
Propaedeuticities: none **Is a propaedeuticity for:**		
Types of examinations and other tests: Written and oral		

Course: Superconducting Quantum Technologies	**Teaching Language:** English
SSD (Subject Areas): FIS/03	**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C
Teaching Methods: In-person, lectures and lab experimental activities	
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The course focuses on scientific and educational - training activities in the field of the experimental study of condensed matter physics, superconducting devices, macroscopic quantum effects and quantum electronics. Skills and methods necessary for low-noise measurements at cryogenic temperatures of nanoscale devices and quantum circuits.	
Objectives: The course is aimed at providing the fundamental aspects of superconducting quantum computation. We intend to propose an experimental path, within which the student will have the chance to understand and apply concepts of quantum information science to real devices. The student will be able to perform spectroscopic and time domain measurements on superconducting quantum bits. For this purpose, Python softwares will be used for programming the control sequence of a quantum bit and the study of superconducting resonators.	
Propaedeuticities: Applied Quantum Systems **Is a propaedeuticity for:** None	
Types of examinations and other tests: Oral test with discussion of practical tests carried out in the laboratory	

Course: Nonlinear Systems		**Teaching Language:** English
SSD (Subject Areas): ING/INF-04		**CREDITS:** 6
Course year: II	**Type of Educational Activity:** C	
Teaching Methods: In-person		
Contents extracted from the SSD declaratory consistent with the training objectives of the course: The sector studies the methods and technologies for the processing of information aimed at the automation of plants, processes and dynamic systems in general. Despite the physical-structural differences existing between these types of systems, they lend themselves to being represented, modeled and simulated, and finally managed and controlled, using methodological tools that are largely invariant with respect to the particular application domain considered.:		
Objectives: The aim of the course is to introduce students to the foundations of the mathematical theory of nonlinear systems of ODEs and to illustrate the theory via some representative examples from applications.		
Propaedeuticities: None **Is a propaedeuticity for:** None		
Types of examinations and other tests: Oral exam and project discussion		

ANNEX 2.2

DEGREE PROGRAM DIDACTIC REGULATIONS

QUANTUM SCIENCE AND ENGINEERING

CLASSE LM-44/LM-120 (c.u.)

School: : Politecnica e delle Scienze di Base

Department: Fisica "Ettore Pancini"

Didactic Regulations in force since the academic year 2024-2025

Training Activity: under Art. 10, c. 5, letter d	**Training Activity Language:** English
Content of the activities consistent with the training objectives of the course: Other knowledge useful for job placement; IT and telematics skills; training and orientation periods, that contribute to the achievement of the CdS objectives	**CFU:** 3
Course year: II	**Type of Training Activity:** F
Teaching Methods: The activities can take place in person, remotely or by participating in schools, internships and physics promotion and dissemination events.	
Objectives: The main purpose of these training activities is to enable the student to acquire further knowledge and/or skills that are useful for completing his/her education, through the acquisition of further knowledge useful for his/her studies, and for the development of relational and organizational skills. or entering the world of work.	
Propaedeuticities: none **Is a propaedeuticity for:** none	
Types of examinations and other tests: The credits relating to these activities are assigned by the CCD coordinator upon presentation of suitable documentation.	

Training Activity: under Art. 10, c. 5, letter d	**Training Activity Language:** English
Content of the activities consistent with the training objectives of the course: Training and orientation internships	**CFU:** 6
Course year: II	**Type of Training Activity:** F

Teaching Methods: Activities in presence or remotely, depending on the type of training or orientation internship
Objectives: The aim of the activity is to have the student carry out a training and/or orientation internship useful for developing skills consistent with the professional activities envisaged by his study path and for entering the world of work.
Propaedeuticities: none **Is a propaedeuticity for:** none
Types of examinations and other tests: The credits for these activities will be recognized by the CCD Coordinator on the basis of suitable documentation certifying the completion of the internship and following a positive evaluation by a CCD commission.