COURSE OF STUDY *Physics (LM-17)*

ACADEMIC YEAR *2024-2025*

ACADEMIC SUBJECT *Quantum Information*

General information	
Year of the course	1st
Academic calendar (starting and ending date)	2nd semester: March - May 2025
Credits (CFU/ECTS):	6
SSD	FIS/02
Language	English
Mode of attendance	Recommended, not compulsory

Professor/ Lecturer	
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Virtual room	
Office Hours (and modalities: e.g., by appointment, on line, etc.)	Upon request

Work schedule			
Hours			
Total	Lectures	Hands-on (laboratory, workshops, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
150	32	30	88
CFU/ECTS			
6	4	2	

Learning Objectives	
Course prerequisites	Quantum Mechanics

Teaching strategies	
Expected learning outcomes in terms of	
Knowledge and understanding on:	o Understand the scientific method, the nature, and the methods of research in Physics o Knowledge of quantum information and quantum technologies o Acquire critical thinking, creativity, analytical ability. o Understand physical phenomena and focus on their precise formulation. o Understand the meaning of the mathematical (most concise) description of the physical world. o Define objectives, benchmarks, learning targets and standards. o Apply the powerful methods of theoretical physics to other fields and disciplines. o Acquire the ability to judge correctness. o Become aware of methods and tools of investigation.

	o Stimulate and direct collaborative learning and individual understanding.
Applying knowledge and understanding on:	o Ability to identify the essential elements of a phenomenon o Ability to use analogy to apply known solutions to new problems (problem solving) o Ability to use analytical and numerical mathematical computation tools o Judge the value of acquired knowledge and methods o Estabilish evaluation criteria and standards, both quantitative and qualitative o Compare, contrast, distinguish, describe and finally identify physical phenomena
Soft skills	● **Making informed judgments and choices** o Ability to work with increasing levels of autonomy, including taking responsibility in project planning and managing facilities o Judge the value of acquired knowledge. Establish evaluation criteria and standards, both quantitative and qualitative o Compare, contrast, distinguish, describe novel technologies and the underlying physical phenomena ● **Communicating knowledge and understanding** o Competence in communication in Italian and English in advanced fields of Physics o Grasp communication accurately, become able to adopt different forms of presentation o Master physics and science communication o Make examples that are not misleading and foster scientific understanding ● **Capacities to continue learning** o Acquisition of basic knowledge tools for continuous learning and knowledge updates o Summarize the acquired knowledge and identify central meaning and crucial points o Continuously update scientific knowledge.
Syllabus	
Content knowledge	**States and Ensembles.** Axioms of quantum mechanics, The Qubit, Spin-1/2, Photon polarizations, The density operator, The bipartite quantum system, Bloch sphere, Schmidt decomposition, Entanglement, Ambiguity of the ensemble interpretation, Convexity, Ensemble preparation, Faster than light? Quantum erasure, The HJW theorem, How far apart are two quantum states?, Fidelity and Uhlmann's theorem, Relations among distance measures. **Measurement and Evolution.** Orthogonal measurement and beyond, Orthogonal Measurements, Generalized measurements, Quantum channels, The operator-sum representation, Reversibility, Quantum channels in the Heisenberg picture, Quantum operations, Linearity, Complete positivity, Channel-state duality and the dilation of a channel, Channel-state duality, Stinespring dilation, Axioms revisited, Three quantum channels, Depolarizing channel, Dephasing channel, Amplitude-damping channel, Master equations for open quantum systems, Markovian evolution, The Liouvillian, Damped harmonic oscillator, Non-Markovian noise, Gaussian phase noise, Spin echo, Qubits as noise spectrometers, Spin-boson model at nonzero temperature. **Quantum Entanglement.** Nonseparability of EPR pairs, Hidden quantum information, Einstein locality and hidden variables, The Bell inequality, Three quantum coins, Quantum entanglement vs. Einstein locality, More Bell inequalities, CHSH inequality, Maximal violation, Quantum strategies outperform classical strategies, All entangled pure states violate Bell inequalities, Photons, Experiments and loopholes, Using entanglement, Dense coding,Quantum teleportation, Quantum teleportation and maximal entanglement, Quantum

	software, Quantum cryptography, EPR quantum key distribution, No cloning, Mixed-state entanglement, Positive-partial-transpose criterion for separability, Nonlocality without entanglement, Multipartite entanglement, Three quantum boxes, Cat states, Entanglement-enhanced communication, Manipulating entanglement.
Texts and readings	J. Preskill, Lecture Notes in Physics 229: Quantum Information and Computation, Cap. 2-3-4, available online http://theory.caltech.edu/~preskill/ph219/ph219_2020-21.html G. Benenti, G. Casati, D. Rossini and G. Strini, Principles of Quantum Computation and Information: A Comprehensive Textbook (World Scientific, Singapore, 2019)
Notes, additional materials	Course lecture notes
Repository	

Assessment	
Assessment methods	Oral examination
Assessment criteria	● **Knowledge and understanding** o Demonstrate knowledge and understanding of content and concepts through developed and accurate descriptions, explanations and examples. ● **Applying knowledge and understanding** o Apply concepts in practically relevant situations ● **Autonomy of judgment** o Consistently identify and analyze sources and data and consistently identify different views and their implications ● **Communicating knowledge and understanding** o Organize information and ideas effectively and communicate information and ideas in a way that is completely clear ● **Communication skills** o Communicate information and ideas in a way that is completely appropriate to the audience and purpose ● **Capacities to continue learning** o Development of effective continuous assessment instruments and methods, and selection of appropriate continuous assessment instruments and methods
Final exam and grading criteria	Knowledge of the foundations and principles of quantum physics and information theory. Comprehension of quantum-enhanced methods and quantum applications.
Further information	
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