

MASTER'S DEGREE IN QUANTUM TECHNOLOGIES

Compulsory subjects:

Fundamentals of quantum technologies

- Historical and conceptual introduction. First and second quantum revolutions.
- Quantum theory postulates and mathematical tools.
- Density operator. Pure and mixed states.
- Reversible transformations.
- Composite systems and entanglement.
- Schmidt decomposition.
- Purification.

Comments: This subject will be taught first in order to standardize the knowledge of students from different backgrounds.

Advanced quantum theory

- Quantum Many Body systems and advanced quantum mechanics.
- Quantum optics.
- Open quantum systems.
- Topology in quantum mechanics.

Theory of quantum information

- Introduction.
- Probability theory.
- Classical information theory.
- Quantum entropies.
- Cryptography.
- Quantum Channels.
- Entanglement, Bell inequalities and non-locality.
- Protocols.
- Basic concepts: qubits, logic gates, universality.
- Quantum Algorithms.
- Introduction to Qiskit.
- Noise and error correction.

- Quantum complexity.
- Applications.

Elective subjects:

Implementation of quantum technologies

- Implementations for quantum communication.
- Platforms for quantum computation and simulation (spin, superconducting, ions and atom qubits)
- Sensors and metrology.

Quantum cryptography and communication

- Introduction, classical and quantum cryptography.
- Protocols for key distribution.
- Security.
- Limitations.
- Quantum networks.
- Quantum repeaters.
- Quantum hacking.
- Applications.

Open quantum systems and quantum thermodynamics

- Markovian dissipation.
- Extended systems.
- Systems strongly coupled to the bath.
- Non-markovian models.
- Quantum thermodynamics.
- Quantum thermal machines.
- Quantum transport.
- Fluctuations.
- Quantum Phase transitions.

Machine learning and quantum computers

- Introduction to classical machine learning

- Quantum Machine Learning.
- Neural networks (classical and quantum)
- Reinforcement learning (classical and quantum)
- Applications.

Superconducting quantum circuits

- Introduction to superconductivity.
- Quantum theory of circuits.
- Photons, linear elements.
- Superconducting qubits.
- Photon-qubit and qubit-qubit interaction.
- Applications to quantum computers.

Quantum nanophotonics

- Macroscopic quantum electrodynamics.
- Theoretical methods: Green functions, master equations and collective models.
- Light-matter interactions.
- Emitter and cavity, waveguides and 2D materials.
- Nonlinear quantum optics.
- Measurement and spectroscopy.
- Applications.

Quantum technologies with photons and atoms

- Trapping atoms with light.
- Cavity QED and collective effects.
- Ion traps.
- Cold atoms.

Semiconductor and hybrid qubits

- Introduction to semiconductor physics.
- Nanostructures.
- Spin-orbit interaction in semiconductors.
- Atoms and artificial molecules in quantum dots, colour centres and impurities.
- Multicanal electronic qubits.
- Majorana modes and topological quantum computing.
- Hybrid circuits.

Quantum sensors

- Introduction to the theory of sensing and quantum metrology.
- Colour center based sensors.
- Superconducting based sensors.
- Quantum Metrology.
- AFM microscopy.

Micro/nano fabrication for quantum technologies

- Introduction.
- Lithography.
- Process integration for quantum technologies.
- Characterisation techniques.
- Lab sessions: simulation, design and fabrication demonstration.

Quantum technologies laboratory

PART 1:

- Low Temperature Physics.
- Microwave technology.
- Lasing and detectors.

PART 2 (choose 4 from the list):

- Single photon signal analysis (ITEFI-CSIC)
- Single photon sources (INM-CNM)
- Ion trap qubits (U-Granada)
- NV-Center localisation and characterisation (U. Murcia)
- Coherent control of spin qubits (INMA-CSIC)
- Josephson Junctions and SQUIDS (INMA-CSIC)
- Spectroscopy of nanowire (UAM)
- Hybrid Josephson Junctions (UAM)
- Single photon detector (INMA-CSIC)