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

• Introductions 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 quits (INMA-CSIC)
• Josephson Junctions and SQUIDS (INMA-CSIC)
• Spectroscopy of nanowire (UAM)
• Coulomb blockade in nanowires (UAM)
• Hybrid Josephson Junctions (UAM)
• Single photon detector (INMA-CSIC)