QUARMEN
Erasmus Mundus Joint Master
QUANTUM SCIENCE & TECHNOLOGY

Master 2 (2nd year) QUARMEN 2025-2026
(Semester 3 – UPSACLAY)

*During the third semester at Université Paris-Saclay, QUARMEN students will take both specialized courses specific to the QUARMEN programme and shared courses with another master's program, QLMN (*Quantum, Light, Materials and Nano Sciences*). This programme is organized into three tracks:*
1. Light and Matter
2. Condensed matter
3. Nanodevices and Technologies

Organization of the semester

30 ECTS: 15 ECTS (Sept-Nov) + 15 ECTS (Dec-Feb).

First period (September-November), 15 ECTS:
Compulsory courses:
- Introduction to 2nd quantization (3 ECTS)
- Superconductivity from atoms to circuits (3 ECTS)
+ 3 other courses (3 ECTS each) from the 3 QLMN paths*

Second period (December-February), 15 ECTS:
Compulsory course:
- Theory of quantum matter in the era of q information (3 ECTS)
+ 4 other courses (3 ECTS each) from the 3 QLMN paths.

You can take additional courses, but only the 30 ECTS credits you submit for validation will be included in the semester average.
Extra courses cannot replace any failed exams within those 30 ECTS.
While they may appear on your transcript, they will not contribute to the overall average.

Syllabus of QLMN courses: https://www.master-qlmn.universite-paris-saclay.fr/

Light and Matter (LM)
FIRST PERIOD (September-November) - 15 ECTS:
Mandatory courses (3 ECTS each): - Introduction to 2nd quantization - Superconductivity from atoms to circuits
+ 3 other courses (3 ECTS each) from the 3 paths
Light Matter interaction
Physics of Quantum Information: qubits, entanglement and decoherence
Non-Equilibrium Statistical Physics and Phase Transitions
Laser Physics
Non-Linear Electromagnetism
Quantum molecular physics
QLMN COURSES NOT AVAILABLE FOR QUARMEN: - Optic Labwork - Projet industriel
SECOND PERIOD (December-February) - 15 ECTS
Mandatory course: - Theory of quantum matter in the era of quantum information* - Quarmen track (3 ECTS)
+ 4 other courses (3 ECTS each) from the 3 paths
Recent Experiments in Quantum Information
Quantum technologies: communication, computing and sensors
Optical Excitations and quantum optics at the nanoscale (Excitons physics)
Fundamentals of Nanophotonics
Quantum Sensing
Molecular Quantum Dynamics
Quantum communication
Ultracold Molecules and Rydberg atoms
Near Field Microscopy
Ultracold Atoms and Quantum Simulators
Biophotonics
Plasma Physics
Manipulation de Systèmes Quantiques Simples
Dynamique réactionnelle photo-induite
Technologie des Lasers
Fonctions et intégration photonique
Optique adaptative
Optique de l’extreme
Impulsion optiques ultra-breves
Structure Moléculaire et Transition Optique
Other courses from “ND” or “CM” track when compatible with the schedule.
QLMN COURSES NOT AVAILABLE FOR QUARMEN: *- Optics labwork 2*

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Condensed Matter (CM)
FIRST PERIOD (September-November) - 15 ECTS:
Mandatory courses (3 ECTS each): - Introduction to 2nd quantization - Superconductivity from atoms to circuits
+ 3 other courses (3 ECTS each) from the 3 paths
Light matter interaction
Concepts of quantum and topological matter (replaces Quantum theory of condensed matter)
Non-Equilibrium Statistical Physics and Phase Transitions
Nanomagnetism & Spintronics
Solid states devices
Integrated optics and nanophotonics
Physical-chemistry of low dimensional materials
QLMN COURSES NOT AVAILABLE FOR QUARMEN: - Labworks - Microscopy and spectroscopy
SECOND PERIOD (December-February) - 15 ECTS
Mandatory course: - Theory of quantum matter in the era of quantum information* - Quarmen track (3 ECTS)
+ 4 other courses (3 ECTS each) from the 3 paths
Recent Physics experiments in Quantum technologies
Quantum technologies : communication, computing, and sensors
Optical Excitations and quantum optics at the nanoscale (Excitons physics)
Fundamentals of nanophotonics
Quantum sensing
Energy harvesting in nanostrcutures
Nanoelectronics and molecular electronics
Numerical Simulations
Quantum transport
Interactions in condensed matter physics (replaces Topology)
Fundamentals of micro and nanofabrication
Quantum computing
Outstanding compounds
Other courses from “ND” or “LM” track when compatible with the schedule.
QLMN COURSES NOT AVAILABLE FOR QUARMEN: - Research project - Photovoltaics - Mobile charges: from semiconductors to biology

Nanodevices and Technologies (ND)
FIRST PERIOD (September-November) - 15 ECTS:
Mandatory courses (3 ECTS each): - Introduction to 2nd quantization - Superconductivity from atoms to circuits
+ 3 other courses (3 ECTS each) from the 3 paths
Fundamentals of Micro and Nanofabrication
Advanced micro and nanofabrication
Applied magnetic materials for spintronics and information technologies
Nanoelectronics and molecular electronics
Solid states devices
Integrated optics and Nanophotonics
Physics of MEMS
Micro and nanodevices for biology and diagnostic
QLMN COURSES NOT AVAILABLE FOR QUARMEN: - Labworks - Microscopy and spectroscopy
SECOND PERIOD (December-February) - 15 ECTS
Mandatory course: - Theory of quantum matter in the era of quantum information* - Quarmen track (3 ECTS)
+ 4 other courses (3 ECTS each) from the 3 paths
Recent Experiments in Quantum Information
Quantum technologies: communication, computing and sensors
Optoelectronics
Circuit nanoarchitecture and deep learning
Nanomedicine and nanotoxicology
Other courses from “LM” or “CM” track when compatible with the schedule.
QLMN COURSES NOT AVAILABLE FOR QUARMEN: - Technological project - Research project

1. Syllabus of "Theory of quantum matter in the era of quantum information"

30 hours – 3 ECTS
Lecturer: Leonardo Mazza (LPTMS – Univ. Paris-Saclay)

Goal: to introduce the students to the most recent literature that starting from 1990s has proposed a completely new viewpoint on quantum many-body physics leveraging on the notion of entanglement.

Part 1: Quantum spin chains and the theory of entanglement

In this part we introduce and discuss quantum spin chains, a paradigmatic theorist's sandbox for understanding quantum matter. After introducing some powerful elementary solution techniques, we will inspect the properties of these setups using the tools developed by quantum information theorists, and specifically entanglement. Several models and solution techniques will be presented, that give access to different physical phenomena.

– Recap: One qubit, many qubits, Schmidt decomposition, entanglement entropies
– Quantum spin chains: a theorists' sandbox (gapped vs. gapless etc. - link with quantum computer/hardware). Examples (AKLT model, Majumdar-Ghosh model...)
– Many-body quantum states through the lens of entanglement (area/log/volume size-scaling of entanglement).
– Examples (product states, XXX ground state, symmetry-breaking Ising)
– The Jordan-Wigner transformation
– Examples (entanglement in free-fermion systems)

Part 2: Matrix-product states, ground states and excited states

In this part we introduce matrix-product states, a generalization of product states with an enormous practical impact. We will discuss the fact that they can faithfully describe the properties of the ground state of some quantum spin chains, but also show counterexamples. We will discuss area-law theorems for entanglement as the unifying framework for understanding the ground states of quantum spin chains.

– Product states and matrix-product states
– The ground state of some quantum spin chains is a matrix-product state. Examples (AKLT / Majumdar-Ghosh)
– The ground state of some quantum spin chains is not a matrix-product state. Examples (XXX model)
– Entanglement area laws for ground states
– A unifying view on excited states: the eigenstate thermalization hypothesis
– Exam simulation

2. Syllabus of "Superconductivity: from atoms to circuits"

30 hours – 3 ECTS
Lecturers: Francesca Chiodi, Marco Aprili, Julien Gabelli (CNRS – Univ. Paris-Saclay)

Introduction: Discovery, Meissner-Ochenfeld effect, Critical field (typeI/II), Thermodynamics of the superconductivity transition, London theory (introduction). Pippard theory (introduction). Josephson effect. The RSJ model. Macroscopic Quantum Tunneling

BCS theory at T=0 . The Cooper's problem Effective interaction – BCS Hamiltonian. BCS Wave function (looking for the ground state). Variational method to find pair wave function, gap equation, energy condensation

BCS theory at T>0. Excited states. Bogoliubov transform. Dispersion relation, density of states. Tunneling spectroscopy : tunneling current from the Fermi golden rule. Variational methods.
Electrodynamics of a superconductor. Perturbative Hamiltonian. Linear response theory. Conductivity, Meissner effect.

Inhomogeneous systems. BdG equations. Pair breaking effects. Vortex states and Caroli-de-Gennes bound states. Spin dependent scattering : Shiba bound states. Spin dependent interfaces : the pi-junction

Strong coupling and unconventional superconductivity. Gap equation for strong coupling superconductors. Spin dependent pairing mechanisms. Order parameter symmetry. High Tc superconductors.