Course guide
230578 - QS - Quantum Simulators with Ultracold Quantum Gases

Last modified: 29/05/2026

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 1004 - UB - (ENG)Universitat de Barcelona.

Degree: MASTER'S DEGREE IN PHOTONICS (Syllabus 2013). (Optional subject).
ERASMUS MUNDUS MASTER'S DEGREE IN PHOTONICS (Syllabus 2024). (Optional subject).

Academic year: 2026 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: BRUNO JULIA DIAZ

Others: Primer quadrimestre:
BRUNO JULIA DIAZ -10
LETICIA TARRUELL PELLEGRIN - 10

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE7. Ability to understand optical engineering as an economic and business activity considering, among others, social, ethical and sustainability aspects
CE9. Ability to synthesize and present photonics research results according to the procedures and conventions of scientific presentations in English.
CE2. Demonstrate the understanding of the peculiarities of the quantum model for light-matter interaction.

Generical:
CG4. Ability to understand the generalist and multidisciplinary nature of photonics, seeing its application, for example, to medicine, biology, energy, communications or industry
CG1. Ability to project, design and implement products, processes, services and facilities in some areas of photonics, such as photonic engineering, nanophotonics, quantum optics, telecommunications and biophotonics.
CG2. Ability to modeling, calculate, simulate, develop and implement in research and technological centers and companies, particularly in research, development and innovation tasks in all areas related to Photonics.

Transversal:
CT1. ENTREPRENEURSHIP AND INNOVATION. Knowing and understanding the mechanisms on which scientific research is based, as well as the mechanisms and instruments for transferring results between the different socioeconomic agents involved in R&D&I processes.
CT4. SOLVENT USE OF INFORMATION RESOURCES. Manage the acquisition, structuring, analysis and visualization of data and information in the field of the specialty and critically assess the results of this management.
CT5. ENGLISH. Accredit an adequate level of this language, both orally and in writing, in line with the needs that the graduates will have.
CT3. TEAMWORK. Be able to work as a member of an interdisciplinary team, either as another member, or performing management tasks in order to contribute to developing projects with pragmatism and a sense of responsibility, assuming commitments taking into account the available resources.

Basic:
CB7. Students should know how to apply the knowledge acquired and their problem-solving ability in new or little-known environments within broader (or multidisciplinary) contexts related to their area of ¿¿study.
CB10. Students should possess the learning skills that allow them to continue studying in a way that will be largely self-directed or autonomous.
CB8. Students should be able to integrate knowledge and face the complexity of formulating judgments based on information that, being incomplete or limited, includes reflections on the social and ethical responsibilities linked to the application of their knowledge and judgment.

TEACHING METHODOLOGY

- Lectures
- Activities

LEARNING OBJECTIVES OF THE SUBJECT

This course will cover recent developments in the field of quantum simulation and quantum computing with neutral atoms, with a focus on three aspects: the emulation of synthetic gauge fields to investigate quantum Hall physics, the investigation of Hubbard models with ultracold atoms in optical lattices, and the use of arrays of atoms trapped in optical tweezers and excited to Rydberg states for both quantum simulation and quantum computing.

STUDY LOAD

Type	Hours	Percentage
Self study	51,0	68.00
Hours large group	24,0	32.00

Total learning time: 75 h

CONTENTS

Quantum simulation of artificial gauge fields

Description:
Basics of spin-orbit coupling and quantum Hall physics. Neutral atom realizations of spin-orbit coupling and synthetic magnetic fields: Raman coupling, rotating BECs and Floquet engineering.

Full-or-part-time: 6h
Theory classes: 6h

Quantum simulation of strongly-correlated materials

Description:
Basics of optical lattices. Band structure. Quantum-gas microscopy. Bose-Hubbard model and superfluid - Mott insulator transition. Fermi Hubbard model and quantum magnetism.

Full-or-part-time: 6h
Theory classes: 6h

Quantum simulation and quantum computing with neutral atoms

Description:
Basics of Rydberg physics. Preparation and manipulation of ordered arrays. Ising and XY models. Going beyond spin models. Quantum computing with neutral atoms. Implementation of quantum error correction codes.

Full-or-part-time: 4h
Theory classes: 4h

GRADING SYSTEM

Attendance to be evaluated: >80% of the lecture time
- Exam: written or oral (60%)
- Homework assessments (40%)

BIBLIOGRAPHY

Basic:
- Pethick, C. J.; Smith, H. Bose-Einstein condensation in dilute gases. Cambridge University Press, 2008. ISBN 9780521846516.
- Pitaevskii, L.P.; Stringari, S. Bose-Einstein condensation. Oxford: Clarendon Press, 2003. ISBN 9780198507192.
- Cooper, N.R. "Rapidly rotating atomic gases". Advances in Physics [on line]. vol. 57, num 6, October 2008 [Consultation: 24/11/2016]. Available on: http://www.informaworld.com/openurl?genre=journal&issn=0001-8732.- Dalibard, J.; Gerbier, F.; Juzeliunas, G.; Öhberg, P. "Artificial gauge potentials for neutral atoms". Reviews of Modern Physics [on line]. Vol. 83, Iss. 4, October - December 2011 [Consultation: 24/11/2016]. Available on: http://journals.aps.org/rmp/.

Complementary:
- Lewenstein, M.; Sanpera, A.; Ahufinger, V. Ultracold atoms in optical lattices : simulating quantum many-body systems. Oxford: Oxford University Press, 2012. ISBN 9780199573127.
- Bloch, I.; Dalibard, J.; Nascimbène, S. "Quantum simulations with ultracold quantum gases". Nature Physics [on line]. num 8, p.267-276, 2012 [Consultation: 24/11/2016]. Available on: http://www.nature.com/nphys/index.html.- Esslinger, T. "Fermi-Hubbard physics with atoms in an optical lattice". Annual Review in Condensed Mater Physhics [on line]. vol. 1, 20101 [Consultation: 24/11/2016]. Available on: http://www.annualreviews.org/eprint/cpKn26dCPrA4kV8TCzWw/full/10.1146/annurev-conmatphys-070909-104059.- Giorgini, S.; Pitaevskii, L.P.; Stringari, S. "Theory of ultracold atomic Fermi gases". Review of Modern Physics [on line]. vol. 80, issue 4, oct 2008 [Consultation: 24/11/2016]. Available on: http://journals.aps.org/rmp/.- Ketterle, W.; Zwierlein, M. "Making, probing and understanding ultracold Fermi gases". Proceedings of the International School on Physics Enrico Fermi 2006 [on line]. [Consultation: 24/11/2016]. Available on: https://arxiv.org/abs/0801.2500.

RESOURCES

Hyperlink:
- Lectures du College de France by J. Dalibard. Courses 2013 and 2014.. http://www.phys.ens.fr/ dalibard/CdF/2013/Cours_2013.pdf http://www.phys.ens.fr/ dalibard/index_en