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

Last modified: 14/12/2023

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).

Academic year: 2023 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: Consultar aquí / See here: https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/responsables-assignatura

Others: Consultar aquí / See here: https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/professorat-assignat-idioma

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 the most recent developments in quantum simulation with ultracold quantum gases. In the last years these systems have emerged as an ideal playground for the simulation of many-body quantum phenomena thanks to the large degree of control and excellent isolation from the environment. The lecture will cover recent topics of the field: fermionic gases, artificial gauge fields for quantum Hall physics, Josephson junctions and macroscopic quantum tunneling, and Hubbard models.

STUDY LOAD

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

Total learning time: 75 h

CONTENTS

Dilute Fermi gases

Description:
The ideal gas of fermions. Weakly interacting fermions. Pairing in dilute Fermi gases (BCS theory). BCS-BEC crossover. Excitations.

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

Artificial gauge fields

Description:
Rotating BECs. Bosonic Hall phases. Mean field theory. Landau Level quantization. Laughlin wave function. Gauge potentials for a two level system. Non-abelian gauge potentials.

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

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Macroscopic quantum tunnelling

Description:
Two-site system. Bosonic Josephson junctions. Semi-classical description. Quantum aspects. SU(2) description. Simulation of Lipkin-Meshkov-Glick model. Experimental realisations. Few-site systems.

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

Optical lattices - Artificial solids

Description:
Optical lattices. Non interacting systems. Bose-Hubbard model. Superfluid - Mott insulator transition. Fermi Hubbard model: Mott insulator and quantum magnetism.

Full-or-part-time: 8h
Theory classes: 8h

GRADING SYSTEM

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

BIBLIOGRAPHY

Basic:
- 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.- Pitaevskii, L.P.; Stringari, S. Bose-Einstein condensation. Oxford: Clarendon Press, 2003. ISBN 9780198507192.
- 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/.- Pethick, C. J.; Smith, H. Bose-Einstein condensation in dilute gases. Cambridge University Press, 2008. ISBN 9780521846516.

Complementary:
- 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.- 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.- Lewenstein, M.; Sanpera, A.; Ahufinger, V. Ultracold atoms in optical lattices : simulating quantum many-body systems. Oxford: Oxford University Press, 2012. ISBN 9780199573127.

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