UNIVERSITAT POLITÈCNICA DE CATALUNYA

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230556 – QS-BEC – Quantum Simulators, Bose Einstein Condensates and Ultracold Quantum Gases

Coordinating unit: 230 - ETSETB Barcelona School of Telecommunications Engineering
Teaching unit: 1022 - UAB - Universitat Autònoma de Barcelona
Academic year: 2015 - 2016
Degree: Master's Degree in Photonics
Erasmus Mundus Master's Degree in Photonics Engineering, Nanophotonics and Biophotonics
ECTS credits: 3 **Teaching languages:** English

Academic staff

Coordinator:	Veronica Ahufinger (UAB)	Veronica.Ahufinger@uab.cat
Other professors:	Artur Polls (UB)	artur@ecm.ub.edu

Degree competences to which the subject contributes

Transversal:
1. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.
2. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.
3. ENTREPRENEURSHIP AND INNOVATION: Being aware of and understanding how companies are organised and the principles that govern their activity, and being able to understand employment regulations and the relationships between planning, industrial and commercial strategies, quality and profit.
4. TEAMWORK: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.

Teaching methodology

Lectures
Activities:
- Discussion sessions and/or seminars

Objectives and short description of the course

This course will provide an introduction into the recent developments of ultracold quantum gases comprising the fields of quantum optics and atomic physics. The achievement of Bose Einstein condensation in 1995 marks the beginning of a new era with unprecedented possibilities of control of many-body physics at a real quantum level. The phenomenon of condensation, has, however, a quantum statistical origin, which leads to many different physical processes that will be discussed. In this course we will give an overview of the state of the art and discuss possible applications.

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Study load

Total learning time: 75h	Hours large group:	22.5h	30%
	Hours medium group:	0h	0%
	Hours small group:	0h	0%
	Guided activity:	2.25h	3%
	Self study:	50.25h	67%

Course index

1. Introduction and motivation

Basic atomic physics. Atomic structure, degeneracy levels and symmetries. Fine and hyperfine levels. Interaction with external fields: Zeeman splitting, AC-Stark shift. Basic processes of atom-light interactions

2. Basic concepts on cooling and trapping of atoms

Light forces on atoms: dipolar force and radiation pressure force. Cooling: Laser cooling. Atomic traps: optical traps, magneto-optical traps, magnetic traps. Optical lattices

3. Bose Einstein Condensation

The ideal gas of bosons. Weakly interacting bosons. Mean field approach: The Gross-Pitaevskii equation, Bogoliubov de Gennes equations, hydrodynamic theory

4. Dilute Fermi gases

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

5. Ultracold gases in optical lattices

Basic concepts beyond mean field: from weakly interacting systems to strongly correlated systems. Quantum simulators. The Bose Hubbard model: superfluid-Mott insulator phase transition.

Qualification system

Attendance to be evaluated: >80% of the lecture time
Written exam (70%)
Homework assessments (30%)

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Bibliography

- **On line**

- Lectures du College de France by C. Cohen-Tannoudji. courses 1998-1999, 1999-2000. http://www.phys.ens.fr/cours/college-de-france/

- **Basic**

- M. Fox, Quantum Optics: An introduction, Oxford Master series in Atomic, Optical and laser Physics, Oxford University Press, 2006.
- P. v. d. Straten, H. Metcalf, Laser Cooling, Springer, 1999.
- P. Meystre, Atom Optics, Springer, 2001.
- -C.J. Foot, Atomic Physics, Oxford Master series in Atomic, Optical and laser Physics, Oxford Univ. Press, 2005.
- -C. Cohen-Tannoudji and D. Guery-Odelin, Advances in Atomic Physics: An overview, World Scientific, 2011.
- -C.J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases, Cambridge University Press, 2002.
- -L.P. Pitaevskii and S. Stringari, Bose Einstein condensation, Oxford University Press, 2004.

- **Advanced**

- M. Lewenstein, A. Sanpera, V. Ahufinger, Ultracold gases in Optical lattices: simulating many-body systems, Oxford University Press, 2012.
- A.J. Legget, Bose-Einstein condensation in the alkali gases: Some fundamental concepts, Rev. Mod. Phys. 73, 307 (2001).
- K. Bongs and K. Sengstock, Physics with coherent matter waves, Rep. Prog. Phys. 67, 907 (2004).
- S. Giorgini, L.P. Pitaevski, S. Stringari, Theory of ultracold Fermi gases, Rev. Mod. Phys. 80, 1215 (2008).