

## ?????? – QS- Quantum Simulators with Ultracold Quantum Gases

**Coordinating unit:**

**Teaching unit:**

**Academic year:** 2016 - 2017

**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:** Bruno Juliá Díaz (UB)

brunojulia@ub.edu

**Other professors:** Leticia Tarruell (ICFO)

leticia.tarruell@icfo.es

### 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, laboratory visits

### Objectives and short description of the course

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

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%



# ?????? – QS- Quantum Simulators with Ultracold Quantum Gases

## Course index

### 1. Dilute Fermi gases (6 hours)

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

### 2. Artificial gauge fields (6 hours)

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.

### 3. Macroscopic quantum tunnelling (4 hours)

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.

### 4. Optical lattices - Artificial solids (8 hours)

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

## Qualification system

Attendance to be evaluated: >80% of the lecture time

Written exam (60%)

Homework assessments (40%)

## Bibliography

- **On line**

- 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/CdF/2013/Cours_2013.pdf)

[http://www.phys.ens.fr/~dalibard/index\\_en.html](http://www.phys.ens.fr/~dalibard/index_en.html)

- **Basic**

- 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.

- N. R. Cooper, Rapidly rotating atomic gases, Advances in Physics 57, 539 (2008)

## ?????? – QS- Quantum Simulators with Ultracold Quantum Gases

- J. Dalibard, F. Gerbier, G. Juzeliunas, P. Öhberg, Artificial gauge potentials for neutral atoms, *Rev. Mod. Phys.* **83**, 1523 (2011)
  
- **Advanced**
  
- M. Lewenstein, A. Sanpera, V. Ahufinger, *Ultracold gases in Optical lattices: simulating many-body systems*, Oxford University Press, 2012.
  
- I. Bloch, J. Dalibard and S. Nascimbène, Quantum simulations with ultracold quantum gases, *Nature Physics* **8**, 267–276 (2012).
  
- T. Esslinger, Fermi–Hubbard physics with atoms in an optical lattice, *Annu. Rev. Condens. Mater. Phys.* **1**, 129–152 (2010), arxiv:cond-mat/1007.0012
  
- I. Bloch, J. Dalibard and W. Zwerger, Many-body physics with ultracold gases, *Rev. Mod. Phys.* **80**, 885–964 (2008), arxiv:cond-mat/0704.3011
  
- S. Giorgini, L. P. Pitaevskii and S. Stringari, Theory of ultracold atomic Fermi gases, *Rev. Mod. Phys.* **80**, 1215 (2008), arXiv:cond-mat/0706.3360
  
- W. Ketterle and M. Zwierlein, Making, probing and understanding ultracold Fermi gases, *Proceedings of the International School on Physics Enrico Fermi 2006, Ultracold Fermi Gases* (eds. M. Inguscio, W. Ketterle and C. Salomon) 95-288 (IOS Press, Amsterdam, 2007), arXiv:cond-mat/0801.2500