

## Course guide

### 230851 - QM - Quantum Matter

**Last modified:** 19/06/2024

**Unit in charge:** Barcelona School of Telecommunications Engineering  
**Teaching unit:** 748 - FIS - Department of Physics.

**Degree:** MASTER'S DEGREE IN ENGINEERING PHYSICS (Syllabus 2018). (Compulsory subject).

**Academic year:** 2024    **ECTS Credits:** 5.0    **Languages:** Catalan, Spanish, English

#### LECTURER

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**Coordinating lecturer:** FERNANDO PABLO MAZZANTI CASTRILLEJO

**Others:** Primer quadrimestre:  
JORDI BORONAT MEDICO - 10  
FERNANDO PABLO MAZZANTI CASTRILLEJO - 10

#### PRIOR SKILLS

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The student should be familiar with the fundamental concepts of quantum mechanics, together with its mathematical grounds. The students must be also familiar with Dirac's notation, must know what a Hamiltonian is, and must be able to solve basic problems in quantum mechanics. She/he should know what a wave function is. The student must also know what a stationary state is, and be able to build up the time evolution of a system once its stationary states are known. He should also know the basics of angular momentum theory in quantum mechanics.

#### REQUIREMENTS

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Quantum Physics.  
Quantum Mechanics.

#### DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

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**Basic:**

CB6. Possess and understand knowledge that provides a basis or opportunity to be original in the development and/or application of ideas, often in a research context

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.

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.

CB10. Students should possess the learning skills that allow them to continue studying in a way that will be largely self-directed or autonomous.

## TEACHING METHODOLOGY

MD1 - Master classes: The contents of the course are exposed in the classroom by a teacher without the active participation of the students.

MD2 - Exposition classes: students are required to perform an oral presentation of a subject that they have prepared previously. This activity can be asked to be individual or in group.

MD4 - Group work: Learning activity that has to be done through collaboration between the members of a group.

MD5 - Report work: students have to present a written report related to the subject.

MD6 - Problem solving: In the problem solving activity, the teaching staff presents an exercise / problem that the students must solve, whether working individually or in a team.

MD8 - Search for information: The search for information, organized as actively seeking information on the part of the students, allows the acquisition of knowledge directly, but also the acquisition of skills and attitudes related to the obtaining of information.

## LEARNING OBJECTIVES OF THE SUBJECT

At the end of the course, the student must:

- 1) Understand and be able to solve perturbation theory problems in quantum mechanics. These include time-independent perturbation theory problems in the non-degenerate and degenerate cases, as well as time-dependent ones.
- 2) Understand and be able to use variational methods in quantum mechanics.
- 3) Understand basic concepts of scattering theory in quantum mechanics. Be able to solve basic problems related to scattering processes.
- 4) Understand the formalism of first and second quantization applied to many body quantum systems, as well as its application to simple systems.
- 5) Understand the magnetic properties of quantum matter as well as its basic microscopic formulation.
- 6) Know the most elementary models describing many-body quantum systems on the lattice.

## STUDY LOAD

Type	Hours	Percentage
Hours large group	48,0	37.21
Self study	81,0	62.79

**Total learning time:** 129 h

## CONTENTS

### 1. Introduction

**Description:**

- 1.1 What problems can be solved in quantum mechanics, and which ones can not be solved exactly.
- 1.2 Relevance of approximate solutions in quantum mechanics. Approximate solutions from perturbation theory and variational methods.
- 1.3 Relevance of scattering theory in quantum mechanics. Relation to experiments.
- 1.4 Discussion about many-body quantum theory as the proper way to understand the physics of several interacting entities.
- 1.5 Introduction to the physics of magnetic systems and its behaviour at the quantum level.
- 1.6 Discussion about the physics of many particles on the lattice.

**Specific objectives:**

- To learn time-dependent and time-independent perturbation theory in quantum mechanics.
- To learn variational methods applied to quantum mechanics
- To understand the concept of cross section in quantum mechanics, and to learn how to calculate it in simple systems. To understand what the T-matrix is and what information provides when studying quantum scattering problems.
- To learn the second quantization formalism.
- To learn mean field theories applied to many-body quantum systems, as well as other relevant models like the Bogoliubov or the Bose-Hubbard ones.
- To understand how quantum magnetic systems are described.

**Related activities:**

- To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.
- To do the homework exercises, and to deliver some of them so as to get evaluation marks.
- To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

**Full-or-part-time:** 7h

Theory classes: 3h

Self study : 4h

### 2. Perturbation Theory and Variational Methods

**Description:**

- 2.1 Time independent perturbation theory: non-degenerate case.
- 2.2 Time independent perturbation theory: degenerate case.
- 2.3 Time dependent perturbation theory. Fermi's golden rule.
- 2.4 Variational methods.

**Specific objectives:**

- The same ones described above

**Related activities:**

- To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.
- To do the homework exercises, and to deliver some of them so as to get evaluation marks.
- To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

**Full-or-part-time:** 35h

Theory classes: 13h

Self study : 22h

### 3. Scattering Theory in quantum mechanics.

**Description:**

3.1 Formulation of the problema. Cross section and differential cross section. Lipmann-Scwinger equation.

3.2 T matrix and Bohr approximation.

3.3 Partial wave expansions and boundary conditions.

3.4 Low energy scattering: scattering length and effective range.

**Specific objectives:**

The same ones described above

**Related activities:**

To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.

To do the homework exercises, and to deliver some of them so as to get evaluation marks.

To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

**Full-or-part-time:** 23h

Theory classes: 8h

Self study : 15h

### 4. The many-body problem in quantum mechanics.

**Description:**

4.1 Description of the problem.

4.2 Particle ndistinguibility. Bose and Fermi statistics. Symmetries of the wave function and symmetries of the operators.

4.3 Second quantization. Creation and anihilation operators. Oerators and observables in second quantization.

4.4 Hartree-Fock approximation. Gross-Pitaevskii equation and Bogoliubov approximation.

**Specific objectives:**

The same ones described above

**Related activities:**

To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.

To do the homework exercises, and to deliver some of them so as to get evaluation marks.

To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

**Full-or-part-time:** 38h

Theory classes: 14h

Self study : 24h

## 5. Magnetic systems.

### Description:

5.1 Polarized and unpolarized free system.

5.2 Ferromagnetic states of matter. Single-particle excitations and particle-hole excitations. Magnons.

5.3 Superconductivity and Cooper pairs. Introduction to BCCS theory.

### Specific objectives:

The same ones described above

### Related activities:

To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.

To do the homework exercises, and to deliver some of them so as to get evaluation marks.

To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

### Full-or-part-time: 16h

Theory classes: 6h

Self study : 10h

## 6. Physics of lattice systems.

### Description:

6.1 Quantum systems on discrete lattices.

6.2 The Hamiltonian of a many-body system on the lattice.

6.3 Fermi and Bose Hubbard models.

### Specific objectives:

The same ones described above

### Related activities:

To read the recommended bibliography in order to get a deeper understanding of the topics covered in class.

To do the homework exercises, and to deliver some of them so as to get evaluation marks.

To write a report on a specific topic related to the subjects treated in the course, such that the student can get a deeper understanding of the problem selected.

### Full-or-part-time: 10h

Theory classes: 4h

Self study : 6h

## GRADING SYSTEM

Depending on the number of students, students will have to either pass a written exam, or present in class a report about something related to the subject of the course, which will also have to be written and delivered to the professor. This will contribute a 60% of the final score, while the remaining 40% will be obtained from the resolution of exercises and/or problems. There is no re-evaluation procedure.

## EXAMINATION RULES.

Will be decided as the course goes on.

## BIBLIOGRAPHY

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### Basic:

- Sakurai, J.J.; Napolitano, J. Modern quantum mechanics. 2nd ed., international ed. Essex (England): Pearson, 2014. ISBN 9781292024103.
- Cohen-Tannoudji, C.; Diu, B.; Laloë, F. Quantum mechanics. 2nd ed. Weinheim, Germany: Wiley-VCH, 2020. ISBN 9783527345533.
- Fetter, A.L.; Walecka, J.D. Quantum theory of many-particle systems [on line]. Mineola: Dover, 2003 [Consultation: 25/10/2018]. Available on: <https://ebookcentral.proquest.com/lib/upcatalunya-ebooks/detail.action?docID=1894791>. ISBN 9780486134758.
- Lipparini, E. Modern many-particle physics: atomic gases, quantum dots and quantum fluids. 2nd ed. Singapore: World Scientific, 2008. ISBN 9789812709325.
- Mahan, G.D. Many-particle physics. 3rd ed. New York: Kluwer Academic : Plenum Publishers, 2000. ISBN 9781441933393.

## RESOURCES

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### Other resources:

None.