Course guide
230851 - QM - Quantum Matter

Last modified: 20/05/2022

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: 2022 **ECTS Credits:** 5.0 **Languages:** Catalan, Spanish, 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

PRIOR SKILLS

The student should be familiar with the foundamental 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

Quantum Physics.
Quantum Mechanics.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Basic:
CB6. (ENG) Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación
CB7. (ENG) Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio.
CB8. (ENG) Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicio.
CB10. (ENG) Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo.

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-degenrate and degenerate cases, as well as time-dependent ones.
2) Understand and be able to use variational methods in qauntum 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
Self study	81,0	62.79
Hours large group	48,0	37.21

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 variatinal 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: 2h
Self study : 2h

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: 24h
Theory classes: 8h
Self study : 16h

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: 36h
Theory classes: 24h
Self study : 12h

4. The many-body problem in quantum mechanics.

Description:
4.1 Description of the problem.
4.2 Particle ndistinguilibility. 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: 39h
Theory classes: 14h
Self study : 25h

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: 12h
Theory classes: 8h
Self study : 4h

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: 12h
Theory classes: 4h
Self study : 8h

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 otained from the resolution of exercices and/or problems. There is no re-evaluation procedure.

EXAMINATION RULES.

Will be decided as the course goes on.

BIBLIOGRAPHY

Basic:
- Sakurai, J.J.; Napolitano, J. Modern quantum mechanics. 2nd ed., international ed. Essex (England): Pearson, 2014. ISBN 9781292024103.
- 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.
- Cohen-Tannoudji, C.; Diu, B.; Laloë, F. Quantum mechanics. 2nd ed. Weinheim, Germany: Wiley-VCH, 2020. ISBN 9783527345533.
- Mahan, G.D. Many-particle physics. 3rd ed. New York: Kluwer Academic : Plenum Publishers, 2000. ISBN 9781441933393.
- Lipparini, E. Modern many-particle physics: atomic gases, quantum dots and quantum fluids. 2nd ed. Singapore: World Scientific, 2008. ISBN 9789812709325.

RESOURCES

Other resources:
None.