UAB
Universitat Autònoma de Barcelona

# Quantum Information

2026/2027

Code: 104408
Credits: 6

| Degree programme | Type | Course |
|---|---|---|
| Computational Mathematics and Data Analytics | OB | 3 |

## Contact lecturer

Name : Alessio Celi

Email : alessio.celi@uab.cat

## Teaching staff

Gabriele De Chiara

Axel Pérez-Obiol Castañeda

## Group languages

You can consult this information at the end of the document.

## Prerequisites

It is advisable to have a good command of algebra, especially of vector spaces and, preferably, of complex Euclidean spaces. It is advisable also to be familiar with the basic concepts of classical information, as delivered in the course "Teoria de la informació" of the first semester.

## Objectives

The course is an introduction to the current perspective of quantum mechanics and its paradigms. With today's technology, many of the most paradoxical quantum effects are no longer just academic curiosities - they have become powerful resources forming the foundation of quantum technologies, which have numerous and surprising practical applications. Some of these applications will be presented in this course, particularly quantum cryptography and quantum computing.

The course is aimed at mathematics students with a strong interest in computer science and data analysis. Therefore, it will be necessary to provide the essential physical background through an introduction to the fundamentals of quantum mechanics, classical cryptography, and classical computing. Some basic concepts from classical information theory will also be reviewed.

The goal of the course is not only to provide an overview of recent advances in quantum information but also to equip students with the basic tools they need to pursue postgraduate studies in this field, should they wish to do so.

## Learning outcomes

- CM30 (Explain the hypotheses of quantum physics, applying them to information processing problems.)

Explain the hypotheses of quantum physics, applying them to information processing problems.
- KM26 (Identify the impact of quantum technologies on computing, cryptography and other communication protocols in the environment.) Identify the impact of quantum technologies on computing, cryptography and other communication protocols in the environment.
- SM32 (Apply the concept of quantum measurement to optimisation problems in simple quantum discrimination, estimation and communication problems.) Apply the concept of quantum measurement to optimisation problems in simple quantum discrimination, estimation and communication problems.

## Contents

0. Review of linear algebra and complex numbers

- Real vector spaces
- Complex numbers
- Complex vector spaces

1. Elements of quantum theory

- Basic principles
- Mixed states
- Unitary operators
- Qubits
- Entangled states
- von Neumann measurement

2. Quantum cryptography

- Information security
- Quantum communications
- Quantum key Distribution

3. Generalized Measurements and Entanglement

- POVM vs. von Neumann
- Bell states and non-locality

4. Quantum information processing

- Digital electronics
- Quantum gates
- Quantum circuits

5. Quantum computation

- Elements of computer science
- Principles of quantum computation
- Deutsch-Jozsa algorithm and other examples

Some of these arguments will be dealt with in the form of seminars

## Learning activities and methodology

| Title | Hours | ECTS | Learning outcomes |
|---|---|---|---|
| Seminars of specific topics | 8 | 0.32 | CM30, KM26, SM32 |
| Theoretical lessons | 28 | 1.12 | CM30, KM26 |

| | | | |
|---|---|---|---|
| Study of the theoretical background | 40 | 1.6 | CM30, KM26 |
| Problem solving | 52.5 | 2.1 | SM32 |
| Problem classes | 14 | 0.56 | CM30, KM26, SM32 |

The course is structured around theoretical classes, problem-solving sessions, and continuous assessment activities.

The theoretical classes are delivered on the blackboard. Some lectures or seminars on specific course topics will generally be given in English and may be presented either on the blackboard or as PowerPoint presentations.

The problem-solving sessions are usually conducted on the blackboard and consist of solving the most significant exercises, whose statements will be made available to students through the Virtual Campus.

There will be three assignments. Their objective is to deepen, consolidate, and expand students' knowledge of the topics and results covered throughout the course. These assignments may include problems and questions of greater complexity and scope. They must be submitted periodically during the course and on pre-agreed dates. These activities aim to encourage independent work.

All materials - problem sets, additional teaching resources, detailed solutions to selected exercises, and announcements related to the course - will be made available to students through the Virtual Campus.

Annotation: within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

## Assessment

## Continuous assessment activities

| Title | Weight | Hours | ECTS | Learning outcomes |
|---|---|---|---|---|
| Retaken exam of theoretical and applied concepts | 70 | 3 | 0.12 | CM30, KM26, SM32 |
| First evaluation exam of theoretical and applied concepts | 35 | 1.5 | 0.06 | CM30, KM26, SM32 |
| Second evaluation exam of theoretical and applied concepts | 35 | 1.5 | 0.06 | CM30, KM26, SM32 |
| Three assessable tests | 30 | 1.5 | 0.06 | CM30, KM26, SM32 |

The assessment is structured to benefit students who regularly attend and follow the course, without penalizing those who opt for the single assessment option.

Continuous Assessment Option

There will be three graded tests. These three tests will cover the content developed during the theory lectures and practiced in the problem-solving sessions. The score for the tests will be:

TT= (TT1+TT2+TT3)/3.

There will be two midterm exams focused solely on the topics covered in the theory and problem-solving

classes. The score for the midterms will be:

Ex=(Ex1+Ex2)/2.

The final grade for the continuous assessment will consist of the midterm exams score (or their retake), Ex, and the tests score, TT, according to the following formula:

Nota= 0.3 * TT + Ex (10 - 0.3* TT)/10.

Access to retakes: Students with a Grade **<** 4.9 who have achieved an Ex $\geq$ 3 score will be eligible to take the midterm retake exam.

Not assessable (No Avaluable): Students with a Grade **<** 4.9 and Ex **<** 3 will receive a final grade of "Not Assessable".

Single Assessment Option

Students who choose this option will be evaluated through a single comprehensive exam. This exam will assess both theoretical and practical problem-solving skills (score Ex from 0 to 7) and a test component (score TT from 0 a 3). The final grade will be calculated as:

Nota = Ex + TT.

This exam can be retaken only for the Ex part, under the same conditions as the continuous assessment, provided that Ex $\geq$ 3.

## Bibliography

The students wil have access to the lessons in pdf format and copies of the Keynote / Powerpoint of the course. For further information, the following bibliography is advisable:

*Theory*

- S.M. Barnett, Quatum Information, Oxford University Press, 2009.
- J. Preskill. Lectures notes on Quantum Computation. Es pot obtenir gratuïtament a la direcció: http://www.theory.caltech.edu/people/preskill/ph229.
- M.A. Nielsen; S.L. Chuang. Quantum Computation and Quantum Information. Cambridge Univ. Press, Cambridge 2000.

• A. Peres. Quantum Theory: Concepts and Methods. Kluwer, Dordrecht 1995.
• D. Applebaum. Probability and Information. Cambridge Univ. Press, Cambridge 1996.
• D. Boumeester; A. Eckert; A. Zeilinger. The Physiscs of Quantum Information. Springer 2000.
• D. Heiss. Fundamentals of Quantum Information. Springer 2002.

*Problems*

- Steeb, Willi-Hans, and Yorick Hardy. *Problems and solutions in quantum computing and quantum information*. World Scientific Publishing Company, 2018.
- C. P. Williams; S. Clearwater. Exploration in Quantum Computing. Springer 1998

## Software

The use of AI is permitted solely as an individual study tool. All graded activities will take place in class. During these activities, the use of AI is strictly prohibited. Any unauthorized use will result in the invalidation of the assessment and will be reported to the degree coordinator.

### Course groups and languages

The information provided is provisional until November 30. After this date, you will be able to consult the language of each group through this link. To access the information, you will need to enter the course CODE

| Type of teaching | Group | Language | Semester | Shift |
|---|---|---|---|---|
| (TE) Theory | 1 | Catalan | second semester | morning-mixed |
| (PLAB) Practical laboratories | 1 | Catalan | second semester | morning-mixed |
| (SEM) Seminars | 1 | Catalan | second semester | morning-mixed |