# Quantum information and computation

**Lecturers**
Nicolas CERF (Coordinator), Ognyan Oreshkov and Jérémie ROLAND

**Course mnemonic**
INFO-H514

**ECTS credits**
5 credits

**Language(s) of instruction**
English

**Course period**
First term

**Campus**
Solbosch

## Course content

Introduction

- Basic principles of quantum mechanics (pure and mixed states, unitary evolution)
- Quantum measurements (projective and positive-operator valued measure)
- Notion of quantum bit
- Quantum no-cloning theorem

Quantum entanglement

- Separability vs entanglement of bipartite states
- Nonlocality (EPR paradox and Bell inequalities)
- Dense coding, teleportation, state merging
- Quantum games

Quantum information theory

- Basic notions of classical information theory
- Quantum source coding (von Neumann entropy)
- Classical accessible information (Holevo bound)
- Quantum channel capacities

Quantum cryptography

- BB84 protocol for quantum key distribution
- Entanglement-based quantum key distribution

Quantum computing

- Quantum circuits and universal gates
- Phase kickback: Deutsch-Jozsa's algorithm
- Amplitude amplification: Grover's search algorithm
- Quantum Fourier transform: Shor's factoring algorithm
- Quantum phase estimation: Kitaev's description of Shor's algorithm

Quantum error correction

- Decoherence
- Classical error correction
- 3-qubit repetition code
- Shor's 9-qubit code
- Fault tolerance (basics)

## Objectives (and/or specific learning outcomes)

The final objectives are:

- to familiarise the students with the basic properties of quantum information, in particular how it differs from classical information and how it can be processed keeping quantum coherence;
- to expose how these properties can be exploited in different communication and computation applications, analyzing in particular the notion of quantum algorithms;
- to confront the students with current challenges in the field of quantum information and computation, both from a physics and computer science perspective

Learning outcomes: At the end of the course students are able to:

- understand the basics of quantum information theory and its main applications;
- solve simple problems in quantum information and computation;
- design and analyse simple quantum algorithms using basic tools such as phase kickback, amplitude amplification, and quantum phase estimation.

## Teaching method and learning activities

- Theory courses
- Exercice sessions
- Project (based on a scientific article)

## References, bibliography and recommended reading

- Michael A. Nielsen and Isaac L. Chuang. Quantum Computation and Quantum Information. Cambridge University Press, 2000
- John Preskill. Lecture notes for the course "Physics 219/ Computer Science 219" at Caltech. See in particular chapter

6 for quantum computation: http://www.theory.caltech.edu/~preskill/ph219/index.html#lecture

- David Mermin. Quantum Computer Science; An introduction. Cambridge Univ Press, 2007

### Course notes

Université virtuelle

## Other information

### Place(s) of teaching

Solbosch

### Contact(s)

- Nicolas CERF (Nicolas.Cerf@ulb.be)
- Jérémie ROLAND (Jeremie.Roland@ulb.be)
- Ognyan ORESHKOV (Ognyan.Oreshkov@ulb.be)

## Evaluation method(s)

Oral examination and Oral presentation

### Evaluation method(s) (additional information)

- Continuous assessment: project (oral presentation of a scientific article)
- Final assessment: open book oral exam

### Determination of the mark (including the weighting of partial marks)

Both the project and the oral exam are graded on a total of 20.

- If both grades are above 10/20, the global grade is their weighted average (the project counts for 20% while the oral exam counts for 80%), rounded to the closest half integer
- If one of the grades is below half, the global grade is the minimum of both grades.

In short, in order to validate the course, the student needs to validate both the project **and** the oral exam.

### Main language(s) of evaluation

English

### Other language(s) of evaluation, if applicable

French

## Programmes

### Programmes proposing this course at the Brussels School of Engineering

MA-IRIF | Master of science in Computer Science and Engineering | finalité Professional/unit 2 and MA-IRPH | Master of science in Physical Engineering | finalité Professional/unit 2

### Programmes proposing this course at the faculty of Sciences

MA-INFO | Master in Computer science | finalité Professional/unit 2