Universidad Europea

1. OVERVIEW

Subject area	Quantum Technologies
Degree	Bachelor's Degree in Physics
School/Faculty	School of Architecture, Engineering and Design
Year	Fourth
ECTS	6 ECTS
Type	Optional
Language(s)	Spanish
Delivery mode	On campus
Semester	First semester

2. INTRODUCTION

Quantum Technologies is an elective subject area on the syllabus for the Bachelor's Degree in Physics at Universidad Europea de Madrid. It is part of the pathway for the three specialities available on the UEM Bachelor's Degree in Physics (Materials, Electronics, and Computing and Data Analysis), providing a cross-curricular overview applicable to different areas of both theoretical and applied physics.

In this context, with the knowledge and skills gained from studying the properties of the physical systems presented during the course, the main aim of the subject area is for students to understand the current leading technological applications that are based on the principles of quantum physics, in the fields of information, communication, computing and states of matter.

As such, students will analyse the typical elements of the quantum systems studied during the course, their current development, technological applications and current limitations and challenges.

"Quantum Technologies" proposes applying physics applications and problem solving to the fields of information, communication, computing and materials. To this end, during the course, the techniques and theoretical tools needed for analytical problem solving will be provided.

This subject area also presents an opportunity, from a skills-building perspective, for students to gain further theoretical knowledge and skills and a deeper understanding of the technological applicability of these developments, as well as to build research skills in different fields of theoretical and experimental physics.

3. SKILLS AND LEARNING OUTCOMES

Key skills (CB, by the acronym in Spanish):

- CB2: Students can apply their knowledge to their work or vocation in a professional manner and possess the skills which are usually evident through the forming and defending of opinions and resolving problems within their study area.
- CB5: Students have developed the learning skills necessary to undertake further study in a much more independent manner.

General skills (CG, by the acronym in Spanish):

- CG2: Ability to plan and perform independent work when managing projects associated with different areas of physics.
- CG3: To understand and express oneself in a language of science other than Spanish in a professional setting.
- CG4: To convey knowledge, procedures, results and scientific ideas in the field of physics, both orally and in writing.
- CG5: To understand diverse phenomena that, despite being physically different, share certain similarities, allowing known solutions to be applied to new problems.

Transversal skills (CT, by the acronym in Spanish):

- CT2: Independent learning: A range of skills in order to choose research, analysis, evaluation and information management strategies from different sources, as well as to learn and put into practice what has been learnt independently.
- CT3: Teamwork: Ability to integrate and collaborate actively with other people, areas and/or organisations to reach common goals.
- CT5: Problem solving: Be able to critically evaluate information, separate complex situations into their constituent parts, recognise patterns, and consider alternatives, different approaches and perspectives in order to find optimal solutions and negotiate efficiently.
- CT7: Leadership: To be able to direct, motivate and guide others, recognising their skills and abilities in order to effectively manage their development and common interests.

Specific skills (CE, by the acronym in Spanish):

- CE06: To understand key experimental models and to perform experiments independently, describing, analysing and critically assessing experimental data.
- CE09: To understand the processes for obtaining materials and the physical fundamentals and uses of materials.

Learning outcomes (RA, by the acronym in Spanish):

- R1: To describe the physics of information processes.
- R2: To describe the basic protocols of quantum communication and its technological applications. To explain how fundamental quantum algorithms work.
- R3: To understand the current state of development and challenges in quantum computing.

The following table shows how the skills developed in the subject area match up with the intended learning outcomes:

Skills	Learning outcomes
CG2, CG3, CT2, CT5, CE06, CE09, CB2, CB5	**R1** To describe the physics of information processes
CG4, CG5, CT2, CT3, CE06, CB2, CB5	**R2**: To describe the basic protocols of quantum communication and its technological applications. To explain how fundamental quantum algorithms work.
CG3, CG4, CE06, CE09, CT5, CT7, CB2, CB5	**R3**: To understand the current state of development and challenges in quantum computing.

4. CONTENTS

The subject is organised into six learning units, which in turn are divided into topics:

Unit 1. Introduction to classical information theory

- The bit.
- 1.2. Logic gates.
- 1.3. Information and entropy.

Unit 2. Quantum information theory

- 2.1. The qubit. The Bloch sphere. Multiple qubits.
- 2.2. Quantum logic gates.
- 2.3. Entanglement.
- 2.4. Density operator. Trace and partial trace.
- 2.5. Quantum teleportation. Superdense coding.
- 2.6. No-cloning theorem.
- 2.7. The monogamy of entanglement.

Unit 3. Quantum cryptography

- 3.1. The BB84 protocol.
- 3.2. The E91 protocol.

Unit 4. Quantum computing

- 4.1. Introduction to quantum algorithms.
- 4.2. Grover's algorithm.
- 4.3. Variational quantum algorithms: QAOA and VQE.
- 4.4. Quantum annealing.

Unit 5. Exotic states of matter

- 5.1. Introduction to superconductivity.
- 5.2. Persistent current.
- 5.3. Perfect diamagnetism.
- 5.4. Type I and type II superconductors.

Unit 6. Introduction to plasma physics

6.1. Plasma properties.

- 6.2. The collision cross-section.
- 6.3. Continuity equations.

5. TEACHING/LEARNING METHODS

The types of teaching/learning methods are as follows:

- Lectures.
- Independent learning and exercises.
- Presentations.

6. LEARNING ACTIVITIES

The types of learning activities, plus the amount of time spent on each activity, are as follows:

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On campus:

Learning activity	Number of hours
Lectures	22
Asynchronous lectures	4
Oral presentations of projects and debates	6
Report writting	21
Assessment	6
Practical activities (problems, written work, projects, workshops and/or lab work)	21
Tutorials	16
Independent working	54
TOTAL	**150**

7. ASSESSMENT

The assessment systems, plus their weighting in the final grade for the subject area, are as follows:

On campus:

Assessment system	Weighting
Individual on-campus knowledge tests (theory and/or practice)	50%
Oral defense	10%
Submission of group and/or individual reports, written work, projects or exercises	30%
Performance observation	10%

On the Virtual Campus, when you open the subject area, you'll find details of your assessable tasks, including the submission dates and assessment procedures for each task.

8. BIBLIOGRAPHY

The reference material for the subject area is as follows:

- M.A. Nielsen & I.L. Chuang. (2010). Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press,

The recommended bibliography is indicated below:

- G. Jaeger. (2007). Quantum Information. An overview. Springer.
- J. Hidary. (2019). Quantum Computing: An Applied Approach. Springer.
- T. Wong. (2022). Introduction to Classical and Quantum Computing. Rooted Grove.
- K. Fossheim & A. Sudbø. (2004). Superconductivity. Physics and Applications. Wiley.
- L. Conde. (2014). An Introduction to Plasma Physics and its Space Applications. Archivo online.