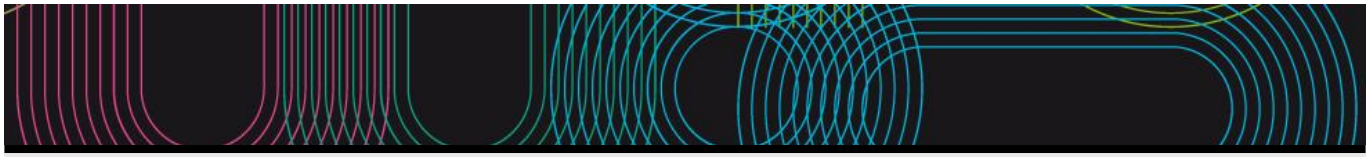

(*)Escola de Enxeñaría de Telecomunicación

(*)Páxina web

(*)

www.teleco.uvigo.es

(*)Presentación

The School of Telecommunication Engineering (EET) is a higher education school of the University of Vigo that offers Bachelor's degrees, Master's degrees and Doctoral programs in the fields of Telecommunications Engineering.

Bachelor's Degree in Telecommunication Technologies Engineering (EUR-ACE®).

The mail goal of the Bachelor's Degree in Telecommunication Technologies Engineering is to form professionals at the forefront of technological knowledge and professional competences in telecommunication engineering. This Bachelor has been recognized with the best quality seals, like the EUR-ACE's. **It has a bilingual option: up to 80% of the degree credits can be taken in English**.

http://teleco.uvigo.es/images/stories/documentos/gett/degree_telecom.pdf

www: http://teleco.uvigo.es/index.php/es/estudios/gett

Master in Telecommunication Engineering

The Master in Telecommunication Engineering is a Master's degree that qualifies to exercise the profession of Telecommunication Engineer, in virtue of the established in the Order CIN/355/2009 of 9 of February.

http://teleco.uvigo.es/images/stories/documentos/met/master_telecom_rev.pdf

www: http://teleco.uvigo.es/index.php/es/estudios/mit

Interuniversity Masters

The current academic offer includes interuniversity master's degrees that are closely related to the business sector:

Master in Cybersecurity: www: https://www.munics.es/

Master in Industrial Mathematics: www: http://m2i.es

International Master in Computer Vision: www: https://www.imcv.eu/

(*)Equipo directivo

MANAGEMENT TEAM

Director: Íñigo Cuíñas Gómez (teleco.direccion@uvigo.es)

Subdirección de Relaciones Internacionales: Enrique Costa Montenegro (teleco.subdir.internacional@uvigo.es)

Subdirección de Extensión: Francisco Javier Díaz Otero (teleco.subdir.extension@uvigo.es)

Subdirección de Organización Académica: Manuel Fernández Veiga (teleco.subdir.academica@uvigo.es)

Subdirección de Calidad: Loreto Rodríguez Pardo (teleco.subdir.calidade@uvigo.es)

Secretaría y Subdirección de Infraestruturas: Miguel Ángel Domínguez Gómez (teleco.subdir.infraestructuras@uvigo.es)

BACHELOR□S DEGREE IN TELECOMMUNICATION TECHNOLOGIES ENGINEERING

General coordinator: Rebeca Díaz Redondo (teleco.grao@uvigo.es)

http://teleco.uvigo.es/images/stories/documentos/comisions/membros_comisions_grao.pdf

MASTER IN TELECOMMUNICATION ENGINEERING

General coordinator: Manuel Fernández Iglésias (teleco.master@uvigo.es)

http://teleco.uvigo.es/images/stories/documentos/comisions/membros_comisions_master.pdf

MASTER IN CYBERSECURITY

General coordinator: Ana Fernández Vilas (camc@uvigo.es)

http://teleco.uvigo.es/images/stories/documentos/comisions/membros_comisions_master_ciberseguridade.pdf

MASTER IN INDUSTRIAL MATHEMATICS

General coordinator: Elena Vázquez Cendón (USC)

UVigo coordinator: José Durany Castrillo (durany@dma.uvigo.es)

http://www.m2i.es/?seccion=coordinacion

INTERNATIONAL MASTER IN COMPUTER VISION

General coordinator: Xose Manuel Pardo López (USC)

UVigo coordinator: José Luis Alba Castro (jalba@gts.uvigo.es)

https://www.imcv.eu/legal-notice/

(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica

Subjects			
Year 1st			
Code	Name	Quadmester	Total Cr.
V05M198V01101	Quantum mechanics I	1st	3
V05M198V01102	Quantum mechanics II	1st	3
V05M198V01103	Fundamentals of quantum information	1st	3
V05M198V01104	Fundamentals of quantum information	1st	3
V05M198V01105	Fundamentals of quantum communications	1st	3

V05M198V01106	Quantum computing tools	1st	3
V05M198V01107	Quantum computing tools	1st	3
V05M198V01108	Quantum computing and machine learning	1st	3
V05M198V01109	Advanced Quantum Information Theory	1st	3
V05M198V01110	Photonic technologies for quantum communication	1st	3
V05M198V01111	Advanced quantum communications	1st	3
V05M198V01112	Quantum optics	1st	3
V05M198V01113	Physical systems for quantum information	1st	3
V05M198V01119	Advanced quantum mechanics	1st	3
V05M198V01120	Quantum computing architectures	1st	3
V05M198V01121	Experimental techniques for quantum information	1st	3
V05M198V01201	Quantum computing and high performance computing	2nd	3
V05M198V01202	Practical applications of quantum computing	2nd	3
V05M198V01203	Bug fixing code	2nd	3
V05M198V01204	Quantum Communications Networks	2nd	3
V05M198V01205	Quantum materials	2nd	3
V05M198V01206	Open systems and quantum thermodynamics	2nd	3
V05M198V01207	Metrology and quantum sensors	2nd	3
V05M198V01208	Numerical methods in quantum computing	2nd	3
V05M198V01209	Introduction to quantum simulation	2nd	3
V05M198V01210	Science and technology of superconductivity	2nd	3
V05M198V01211	Semiconductor photonics	2nd	3
V05M198V01212	Rule-based quantum systems	2nd	3
V05M198V01213	Quantum Communications Laboratory	2nd	3
V05M198V01214	External practices I	2nd	3
V05M198V01215	External practices II	2nd	3
V05M198V01216	Quantum communications via satellite	2nd	3
V05M198V01217	Final Master's Project	2nd	15

IDENTIFYING DATA				
Quantum mechanics I				
Subject	Quantum mechanics I			
Code	V05M198V01101			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	1st
Teaching language	Spanish			
Department				
Coordinator	Paredes Galán, Ángel			
Lecturers	Paredes Galán, Ángel			
E-mail	angel.paredes@uvigo.es			
Web	http://quantummastergalicia.es/info			
General description	This course presents the formalism and basic elements of the quantum mechanics, and more in particular the most adapted to the quantum treatment of the information. It covers the introductory subjects that they will be required by the distinct subjects. It is focused to students that come from of degrees or *másteres in which it have not seen never Mechanical Quantum: engineering, mathematical, etc. Will begin with a review of mathematical methods and will continue with a study in great depth of the axioms of the Quantum Mechanics and his practical consequences.			

Training and Learning Results	
Code	
A1	Understand the domain, concepts, methods and basic techniques of quantum mechanics: mathematical formalism, postulates, operators, matrices, Bloch sphere, photonic states.
B1	To nnow the theoretical foundations of quantum mechanics, the mathematical formalism, the axioms and simpler systems.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	Training and Learning Results
New	A14 A1 A14 A14 B1 B2 C1 C18 C2 C3 C18 C18 C18 D18 D18

Contents	
Topic	
Historical perspective.	Basic experiments.
Complex Hilbert spaces.	Mathematical tools. Elements of linear algebra. Dirac notation.

Operators, eigenvalues and eigenvectors.	Linear operators and matrix notation. External product. Identity operator. Hermitian, unitary and normal operators. Trace of an operator. Commutators. Spectral decomposition. Pauli matrices.
Postulates of quantum mechanics.	Postulates. Measurement. Expected values. Heisenberg uncertainty. Two level systems. Spin states.
Temporal evolution	Hamiltonian operator. Stationary states. Evolution operators.
Density matrix	Pure states and mixed states. Expectation values
Wave mechanics.	Schrodinger equation.

Planning

	Class hours	Hours outside the classroom	Total hours
Lecturing	13	0	13
Seminars	9	0	9
Introductory activities	1	0	1
Autonomous problem solving	0	45	45
Problem and/or exercise solving	0	5	5
Objective questions exam	1	0	1
Problem and/or exercise solving	1	0	1

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description
Lecturing	The professor exposes the contents of the syllabus to the students.
Seminars	Sessions based in the resolution of problems.
Introductory activities	Introduction of the subject.
Autonomous problem solving	Study of the contents and resolution of the proposed exercises.

Personalized assistance

Methodologies	Description
Lecturing	Resolution of doubts in the classroom and in tutorials. To make an appointment for tutorials, write to angel.paredes@uvigo.gal Online tutorials on demand: https://campusremotouvigo.gal/public/961623215 student password: ZuT8euJW
Seminars	Resolution of doubts in the classroom and in tutorials. To make an appointment for tutorials, write to angel.paredes@uvigo.gal Online tutorials on demand: https://campusremotouvigo.gal/public/961623215 student password: ZuT8euJW
Introductory activities	Resolution of doubts in the classroom and in tutorials. To make an appointment for tutorials, write to angel.paredes@uvigo.gal Online tutorials on demand: https://campusremotouvigo.gal/public/961623215 student password: ZuT8euJW
Autonomous problem solving	Resolution of doubts in tutorials. To make an appointment for tutorials, write to angel.paredes@uvigo.gal Online tutorials on demand: https://campusremotouvigo.gal/public/961623215 student password: ZuT8euJW

Assessment

	Description	Qualification	Training and Learning Results		
Problem and/or exercise solving	Autonomous problem solving to show the achievement of the learning results and the development of competences.	60	A1	B1 B2	C1 C2 C3
Objective questions exam	Examination consisting of objective questions to evaluate the acquired knowledge.	20	A1	B1 B2	C1 C2 C3

Problem and/or exercise solving	Examination based on problem solving.	20	A1	B1 B2	C1 C2 C3

Other comments on the Evaluation

Continuous evaluation:

It will consist of three tests:
Resolution of problems outside the classroom 1: Value 30%. Resolution of problems related to the first half of the subject. Continuous attendance and participation in class will be taken into account.
Resolution of problems out of the classroom 2: Value 30%. Resolution of problems related to the second half of the subject. Continuous attendance and participation in class will be taken into account.
Final examination. Value 40%. It will consist of a part of objective questions (20%) and a part of resolution of problems (20%).

Global evaluation:
A single examination consisting of objective questions (20%) and resolution of problems (80%), which will amount to 100% of the qualification of the subject.
This evaluation scheme is valid for both the ordinary and the extraordinary opportunities.
Ethical Commitment: The student is expected to exhibit appropriate ethical behavior. In case of detecting unethical behavior (copying, plagiarism, use of unauthorized electronic devices, etc.), it will be considered that the student does not meet the necessary requirements to pass the subject. In this case, the final grade in the corresponding evaluation opportunity will be 0.0

Sources of information

Basic Bibliography

Notes of the subject,

Complementary Bibliography

David A.B. Miller, **Quantum Mechanics for Scientists and Engineers**, 978-0-521-89783-9, Cambridge University Press, 2008

Michael A. Nielsen and Isaac L. Chuang, **Quantum computation and quantum information**, 0-521-63503-9, Cambridge University Press, 2002

Michel Le Bellac, **Quantum physics**, 978-1107602762, Cambridge University Press, 2006

Recommendations

Subjects that continue the syllabus

Fundamentals of quantum information/V05M198V01103
Quantum mechanics II/V05M198V01102

IDENTIFYING DATA

Quantum mechanics II

Subject	Quantum mechanics II			
Code	V05M198V01102			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/mecanica-cuantica-ii-19342-18435-2-103723			
General description				

Training and Learning Results

Code	
A1	Understand the domain, concepts, methods and basic techniques of quantum mechanics: mathematical formalism, postulates, operators, matrices, Bloch sphere, photonic states.
A2	Know and acquire competence in experimental techniques for the processing of quantum information: interactions, measurements, oscillations, interference, communication systems, ...
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
B10	Knowledge about new solid-state quantum materials, their physical and topological properties.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A1
	A14
	A2
	A3
	A14
	B2
	B10
	C1
	C18
	C2
	C3
	C18
	C18
	C18
	D18
	D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Fundamentals of quantum information

Subject	Fundamentals of quantum information			
Code	V05M198V01103			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	1st
Teaching language				
Department				
Coordinator	Díaz Redondo, Rebeca Pilar			
Lecturers	Díaz Redondo, Rebeca Pilar			
E-mail	rebeca@det.uvigo.es			
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/fundamentos-informacion-cuantica-19342-18435-2-103724			
General description				

Training and Learning Results

Code	
A2	Know and acquire competence in experimental techniques for the processing of quantum information: interactions, measurements, oscillations, interference, communication systems, ...
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
A7	Acquire and know how to apply the basic principles of quantum computing: analyze, understand and implement quantum algorithms, master the appropriate computer languages as well as understand the paradigm of two quantum circuits.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
B3	To know the physical bases that allow encoding and processing information. Understanding of the new rules that Quantum Mechanics imposes for its processing.
B5	To have knowledge of quantum information theory, universal limitations, and their implications for computing, communications, and metrology.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results

New	A14 A2 A14 A3 A14 A7 B2 B18 B3 B18 B18 B5 B18 B18 C1 C18 C2 C18 C3 C18 C18 C18 D18 D18 D18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Fundamentals of quantum information

Subject	Fundamentals of quantum information			
Code	V05M198V01104			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551004&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A7	Acquire and know how to apply the basic principles of quantum computing: analyze, understand and implement quantum algorithms, master the appropriate computer languages as well as understand the paradigm of two quantum circuits.
A8	Know the classical computing algorithms and strategies inspired by quantum computing: tensor networks, product states of matrices, etc.
B3	To know the physical bases that allow encoding and processing information. Understanding of the new rules that Quantum Mechanics imposes for its processing.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A14
	A14
	A14
	A14
	A7
	A8
	B3
	B4
	C1
	C2
	C18
	C3
	C18
	C18
	C18
	C18
	C18
	C18
	C18
	D18
	D18
	D18
	D18
	D18
	D18

Contents

Topic

Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies	
	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Fundamentals of quantum communications

Subject	Fundamentals of quantum communications			
Code	V05M198V01105			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	1st
Teaching language	Spanish Galician			
Department				
Coordinator	Curty Alonso, Marcos			
Lecturers	Curty Alonso, Marcos			
E-mail	mcurty@com.uvigo.es			
Web	http://moovi.uvigo.gal			
General description	This subject provides the student with the basic concepts and techniques of operation of quantum communication systems, with special emphasis on the construction of secure communication channels and the analysis of the protocols on which they are based. This includes quantum key distribution and the different technological implementations, as well as its security analysis.			

Training and Learning Results

Code	
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
A12	Acquire skills for the design and estimation of resources that allow the development of quantum communication channels and networks and distributed computing. Know the state of development and current implementation of quantum networks, and the plans for their expansion.
B11	Knowledge of quantum communications, theoretical principles and experimental implementations, both terrestrial and aerial and via satellite.
B12	To have knowledge about quantum cryptography, its theoretical bases, existing implementations and the challenges they face.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
Knowledge of the main types of quantum key distribution protocols, as well as the theoretical foundations of their security.	A3 A6 A11 A12 B11 B12 C1 C2 C3

Knowledge of the photonic technologies used in these systems, as well as the main experimental platforms, and the ability to understand and evaluate their performance.	A3 A6 A11 A12 B11 B12 C1 C2 C3
Knowledge and ability to apply and derive results from quantum communication protocols.	A3 A6 A11 A12 B11 B12 C1 C2 C3

Contents	
Topic	
1. Introduction to cryptography	1.1. Encryption and authentication of information. 1.2. Classic symmetric key cryptography. One-time-pad scheme. 1.3. Classic public-key and post-quantum cryptography.
2. Quantum cryptography	2.1. Quantum key distribution. 2.2. Security fundamentals.
3. Quantum key distribution protocols	3.1. Prepare-and-measure protocols. 3.2. Protocols based on entanglement and photonic interference. 3.3. Protocols based on continuous variables. 3.4. Data post-processing schemes.
4. Security of quantum key distribution protocols	4.1. Individual, collective and coherent attacks. 4.2. Asymptotic regime and finite regime. 4.3. Security definition. Composability.
5. Technological implementations	5.1. Main experimental platforms. 5.2. Limitations on the secret key generation rate. Photon-number-splitting attack. 5.3. Decoy states.
6. Other quantum communication protocols	6.1. Teleportation. 6.2. Dense coding. 6.3. Bit commitment. 6.4. Quantum radar.

Planning			
	Class hours	Hours outside the classroom	Total hours
Lecturing	18	25	43
Problem solving	4	0	4
Problem and/or exercise solving	0	7	7
Essay	1	10	11
Essay questions exam	2	8	10
*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.			

Methodologies	
	Description
Lecturing	Presentation by the professor of the contents of the subject under study.
Problem solving	Solving problems in the class. Solving problems autonomously by students.

Personalized assistance	
Methodologies	**Description**
Lecturing	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means. You can check the schedule and/or request tutoring sessions at: https://www.uvigo.gal/es/universidad/administracion-personal/pdi/marcos-curty-alonso
Problem solving	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means. You can check the schedule and/or request tutoring sessions at: https://www.uvigo.gal/es/universidad/administracion-personal/pdi/marcos-curty-alonso

Tests	Description
Essay	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means. You can check the schedule and/or request tutoring sessions at: https://www.uvigo.gal/es/universidad/administracion-personal/pdi/marcos-curty-alonso

Assessment

	Description	Qualification	Training and Learning Results		
Problem and/or exercise solving	Resolution of problems and/or exercises.	30	A3 A6 A11 A12	B11 B12	C1 C2 C3
Essay	Realization of a project in groups of students guided by the professor.	30	A3 A6 A11 A12	B11 B12	C1 C2 C3
Essay questions exam	Final exam in which all the contents of the subject are evaluated.	40	A3 A6 A11 A12	B11 B12	C1 C2 C3

Other comments on the Evaluation

There will be two evaluation modalities in the ordinary call: continuous evaluation and global evaluation. The continuous evaluation consists of the delivery of exercises solved individually by each student (30%), of a project performed in group and guided by the professor (30%), and a written exam at the end of the course (40%). The overall evaluation will consist of a single written exam at the end of the course. A student will be considered as opting for the overall assessment if they do not submit the set of exercises. The continuous evaluation prevents a final qualification of not presented.

Sources of information

Basic Bibliography

Complementary Bibliography

Nicolas Gisin, Grégoire Ribordy, Wolfgang Tittel, Hugo Zbinden, **Quantum Cryptography**, https://doi.org/10.1103/RevModPhys.74.145, Rev. Mod. Phys. 74, 145, American Physical Society, 2002

Dagmar Bruss, Norbert Lutkenhaus, **Quantum Key Distribution: from Principles to Practicalities**, https://doi.org/10.1007/s002000050137, AAECC Vol 10, 383-399, Springer, 2000

Hoi-Kwong Lo, Yi Zhao, **Quantum Cryptography**, https://doi.org/10.1007/978-0-387-30440-3_432, Encyclopedia of Complexity and Systems Science 8, 7265-7289, Springer, 2009

Recommendations

Subjects that continue the syllabus

Advanced quantum communications/V05M198V01111
Quantum communications via satellite/V05M198V01216
Quantum Communications Laboratory/V05M198V01213
Quantum Communications Networks/V05M198V01204

IDENTIFYING DATA

Quantum computing tools

Subject	Quantum computing tools			
Code	V05M198V01106			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551006&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
A7	Acquire and know how to apply the basic principles of quantum computing: analyze, understand and implement quantum algorithms, master the appropriate computer languages as well as understand the paradigm of two quantum circuits.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
B6	To acquire knowledge about physical systems capable of implementing information processing in quantum degrees of freedom.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A14
	A14
	A3
	A14
	A14
	A7
	A10
	B4
	B6
	C1
	C2
	C18
	C3
	C18
	C18
	D18
	D18
	D18
	D18
	D18

Contents

Topic

Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies	
	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Quantum computing tools

Subject	Quantum computing tools			
Code	V05M198V01107			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/fundamentos-informacion-cuantica-19342-18435-2-103724			
General description				

Training and Learning Results

Code	
A7	Acquire and know how to apply the basic principles of quantum computing: analyze, understand and implement quantum algorithms, master the appropriate computer languages as well as understand the paradigm of two quantum circuits.
B3	To know the physical bases that allow encoding and processing information. Understanding of the new rules that Quantum Mechanics imposes for its processing.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A7 B18 B3 B4 C1 C2 C3 C18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Quantum computing and machine learning

Subject	Quantum computing and machine learning			
Code	V05M198V01108			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551008&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
B15	To have knowledge of high-level aspects of quantum computing: learning quantum machines, quantum simulators, architectures, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A9
	A10
	B4
	B15
	C1
	C18
	C2
	C18
	C3
	C18
	C18
	C18
	C18
	C18
	C18
	C18
	D18
	D18
	D18
	D18
	D18
	D18
	D18
	D18

Contents

Topic	

Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies	
	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA				
Advanced Quantum Information Theory				
Subject	Advanced Quantum Information Theory			
Code	V05M198V01109			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language	Spanish			
Department				
Coordinator	Fernández Veiga, Manuel			
Lecturers	Díaz Redondo, Rebeca Pilar Fernández Veiga, Manuel			
E-mail	mveiga@det.uvigo.es			
Web				
General description	(*)Este curso presenta, interpreta e aplica os resultados principais da teoría da información cuántica aplicables á transmisión e a compresión de información cuántica.			

Training and Learning Results	
Code	
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
B3	To know the physical bases that allow encoding and processing information. Understanding of the new rules that Quantum Mechanics imposes for its processing.
B13	To be aware of the physical and technical limitations of the implementation of quantum information treatment systems: noise, decoherence, etc., as well as the mitigation or correction strategies that are proposed.
D1	Acquisition of tools and knowledge that allow the development of original and innovative ideas in a business or academic context.
D2	Ability to solve problems in new or little familiar contours within broader (or multidisciplinary) contexts related to their area of study.
D3	Ability to integrate knowledge and deal with complexity before making judgments based on information that, being incomplete or limited, includes reflections on social and ethical responsibilities.

Expected results from this subject	Training and Learning Results
Knowledge and ability to apply known results in Quantum Information Theory to problems, and to develop new results on Quantum Information Theory as well	A3 A11 B3 B13 D1 D2 D3

Contents	
Topic	
1. Quantum channels	a. Review of characterizations of quantum channels: natural, Choi, Kraus, Stinespring b. Examples of channels: preparation, addition, substitution, classical-quantum, quantum-classical, isometric, depolarization, erasure c. Until channels: mixed initial channels, Weyl channels, Schur channels d. Separable channels, separability measures. PPT channels. LOCC channels.
2. Entanglement-assisted classical communications	a. One-shot channel capacity. Bounds b. Asymptotic channel capacity c. Examples

3. Classical communications over quantum channels	a. One-shot channel capacity. Bounds b. Asymptotic channel capacity c. Examples
4. Quantum communications over quantum channels	a. One-shot channel capacity. Bounds b. Asymptotic channel capacity c. Examples

Planning

	Class hours	Hours outside the classroom	Total hours
Lecturing	18	25	43
Problem solving	5	0	5
Problem and/or exercise solving	0	25	25
Essay questions exam	2	0	2

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description
Lecturing	Presentation of theory, scientific results, and examples about quantum communications and quantum protocols.
Problem solving	Practice sessions for problem solving. Also, homework problem sets, to be solved individually by students and returned for grading and assessment.

Personalized assistance

Methodologies	Description
Lecturing	Individual tutoring sessions will be offered to students, covering all the theoretical aspects of the course. Office hours and type of meetings: Manuel F. Veiga. [https://www.uvigo.gal/es/universidad/administracion-personal/pdi/manuel-fernandez-veiga] Rebeca Díaz. [https://moovi.uvigo.gal/user/profile.php?id=11470]
Problem solving	Individual tutoring sessions will be offered to students as assistance for understanding the models and problem solving techniques related to the course topics. Office hours and type of meetings: Manuel F. Veiga. [https://www.uvigo.gal/es/universidad/administracion-personal/pdi/manuel-fernandez-veiga] Rebeca Díaz. [https://moovi.uvigo.gal/user/profile.php?id=11470]

Assessment

	Description	Qualification	Training and Learning Results		
Problem and/or exercise solving	Homework problem sets to be solve individually, written and graded. Two sets of problems with 30% of the final grade each.	60	A3 A11	B3 B13	D1 D2 D3
Essay questions exam	Written exam. Problems.	40	A3 A11	B3 B13	D1 D2 D3

Other comments on the Evaluation

There will be two evaluation modalities in the ordinary call: continuous evaluation and global evaluation. The continuous evaluation consists of the delivery of two sets of written exercises resolved individually by each student, each of which will have a weight of 30% in the final grade, plus a written exam at the end of the course, with a weight of 40%. . The overall evaluation will consist of a single written exam at the end of the course. A student will be considered as opting for the overall assessment if they do not submit the first set of written exercises. The continuous evaluation prevents a final qualification of not presented.

Sources of information

Basic Bibliography

John Watrous, **The theory of quantum information**, Cambridge University Press, 2018

Complementary Bibliography

Sumeet Khatri and Mark M. Wilde, **Principles of Quantum Communication Theory: A Modern Approach**, 2021

Michael A. Nielsen & Isaac L. Chuang, **Quantum Computation and Quantum Information**, Cambridge University PRess, 2011

Recommendations

IDENTIFYING DATA				
Photonic technologies for quantum communication				
Subject	Photonic technologies for quantum communication			
Code	V05M198V01110			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language	Spanish Galician			
Department				
Coordinator	Salgueiro Piñeiro, Jose Ramon			
Lecturers	Michinel Álvarez, Humberto Javier Salgueiro Piñeiro, Jose Ramon			
E-mail	jrs@uvigo.es			
Web	http://quantummastergalicia.es			
General description	(*)A asignatura proporciona os coñecementos básicos sobre dispositivos electrónicos e fotónicos necesarios nun enlace de comunicacións cuántico: láseres e outras fontes ópticas así coma fotodetectores. Tamén se estudan as características e modelos dos canais de transmisión por fibra óptica e no espazo libre			

Training and Learning Results	
Code	
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
B7	To have knowledge of quantum optics and the role and properties of light and its manipulation in quantum information processing and communications.
B11	Knowledge of quantum communications, theoretical principles and experimental implementations, both terrestrial and aerial and via satellite.
B13	To be aware of the physical and technical limitations of the implementation of quantum information treatment systems: noise, decoherence, etc., as well as the mitigation or correction strategies that are proposed.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	
Expected results from this subject	Training and Learning Results
Knowledge of the basic aspects of optical sources and their applications to communications	A6 A11 B7 C1 C2 C3
Knowledge of the basics of optical communication channels, particularly optical fibres	A6 A11 B7 B13 C1 C2 C3

Knowledge of the basics of electromagnetic wave propagation through vacuum and homogeneous media	A6 A11 B7 B13 C1 C2 C3
Knowledge of single-photon production and detection techniques.	A6 A11 B7 B11 B13 C1 C2 C3
Knowledge of the quantum coding methods for the information and their applications to communications cryptography	A6 A11 B7 B11 B13 C1 C2 C3

Contents	
Topic	
1. Optical sources	Einstein□s theory of radiation. Quantum theory of radiation. Lifetime of excited states. Absorption and stimulated emission. Rabi Frequency and coherent population oscillations. Linewith and broadening mechanisms. Rate equations in laser systems Gain coefficient. Homogeneous and inhomogeneous gain saturation. Laser cavities and modes. Lasing threshold and mode amplification Diode lasers fundamentals
2. Channels of transmission	Information channels of information. Codification formats. Wave propagation in homogeneous dielectric media. Gaussian beams. Optical fibres. Propagation modes. Dispersion in optical fibres. Attenuation in optical fibres.
3. Production snd detection of single photons	Photon source characteristics and characterization methods. Overview of single photon sources: parametric down conversion, four wave mixing, quantum dots. Weak coherent pulses vs single photons. Single photon detectors: photomultiplier tubes, semiconductor-based detectors, superconductor-based detectors. Optical coherent detection .
4. Main experimental platforms of QKD.	Discrete variable QKD: polarization, phase and time encoding. Continuos variable QKD: Gaussian modulation, quadrature-amplitude modulation. Fiber based QKD vs Free space QKD. Measurement device independent QKD and Twin field QKD. Device-Independent QKD.

Planning			
	Class hours	Hours outside the classroom	Total hours
Lecturing	15	0	15
Problem solving	10	50	60
*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.			

Methodologies	
	Description
Lecturing	The lecturer presents the contents of the subject projecting the supporting graphical material and attending the questions asked by the students during the presentation.
Problem solving	The lecturer proposes different problems during the lessons, covering the contents of the subject. The students work on such problems on their own with the support of the lecturers.

Personalized assistance	
Methodologies	**Description**
Lecturing	The lecturer answers the questions made by the students during the lesson presentation.

Problem solving	The lecturer attends the student in a personal session to answer the questions and doubts that may arise during the resolution of the problems. Attention may be life, by email or by videoconference at student request.

Assessment

	Description	Qualification	Training and Learning Results		
Lecturing	Questions or simple exercises will be proposed and asked to deliver in before an specified date	30	A6 A11	B7 B11 B13	C1 C2 C3
Problem solving	Students will have to submit, before a dead line, some of the problems proposed along the semester. The total qualification of 70% will be shared among the number of required problems which will not be less than two in order not to overpass a 35% of weight each.	70			

Other comments on the Evaluation

The student has the right to opt for the global assessment according to the procedure and the deadline established by the centre for each call. In such a case the students will take a written examination which may contain problems, exercises and questions related to the different topics of the subject.

If a student does submit none of the problems he/she will receive "not presented" mark.

Second assessment evaluation and End-of-program evaluation: both will be done in the same way as the first assessment evaluation. The students should submit the exercises and problems before the date of the official examination.

Sources of information

Basic Bibliography

Sibley, M., **Optical communications components and systems**, 978-3030343583, 3ª, Cham Springer, 2020

Svelto, O., **Principles of lasers**, 9781461513735, 5ª, ilustrada, Springer Science & Business Media, 2010

Migdall, A. Polyakov, S. V., Fan, J., Bienfang, J. C., **Single photon generation and detection**, 9780123876959, Academic Press;, 2013

Complementary Bibliography

Martín Pereda, J. A., **Sistemas y redes ópticas de comunicaciones**, Pearson Prentice Hall, 2004

Capmany, J., **Fundamentos de comunicaciones ópticas**, Síntesis, 1998

Cerullo, G., Longhi,S., Nisoli, M., Stagira, S., Svelto, O., **Problems in Laser Physics**, 9781461513735, Springer Science & Business Media, 2012, 2012

Wolf, R., **Quantum Key Distribution**, 9783030739904, Springer Science & Business Media, 2012, 2021

Feihu Xu et al., **Secure quantum key distribution with realistic devices**, Rev. Mod. Phys. 92, 025002 □ Published 26 May, 2020

Stefano Pirandola et al., **Advances in Quantum Cryptography**, Adv. Opt. Photon. 12, 1012-1236, 2020

Eleni Diamanti et al., **Practical challenges in quantum key distribution**, Quantum Information 2, 16025, 2016

Recommendations

IDENTIFYING DATA				
Advanced quantum communications				
Subject	Advanced quantum communications			
Code	V05M198V01111			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language	Spanish Galician			
Department				
Coordinator	Curty Alonso, Marcos			
Lecturers				
E-mail				
Web	http://moovi.uvigo.gal			
General description	This course describes and analyzes the security of quantum communication channels, and presents techniques for determining the secret key generation rate in a quantum key distribution system.			

Training and Learning Results	
Code	
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
A12	Acquire skills for the design and estimation of resources that allow the development of quantum communication channels and networks and distributed computing. Know the state of development and current implementation of quantum networks, and the plans for their expansion.
B11	Knowledge of quantum communications, theoretical principles and experimental implementations, both terrestrial and aerial and via satellite.
B12	To have knowledge about quantum cryptography, its theoretical bases, existing implementations and the challenges they face.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	Training and Learning Results
Ability to demonstrate the security of quantum key distribution systems, and to calculate their secret key generation rate.	A11 A12 B11 B12 C1 C2 C3
General knowledge of quantum hacking, and about the practical security of experimental systems.	A11 A12 B11 B12 C1 C2 C3
Knowledge of quantum key distribution networks and the ability to understand and evaluate their performance.	A11 A12 B11 B12 C1 C2 C3

Knowledge of quantum random number generators and the ability to understand and evaluate their performance.	A11 A12 B11 B12 C1 C2 C3

Contents	
Topic	
1. Security of the quantum key distribution.	1.1. Key rate scaling. 1.2. Proof of security based on entropy. 1.3. Other security proofs: Shor-Preskill and that based on complementarity.
2. Quantum hacking.	2.1. Passive attacks and active attacks. 2.2. Hacking the transmitters. Attacks using Trojan Horses. 23. Hacking the receivers. Attacks on detectors. 2.4. Security of experimental implementations.
3. Device-independent quantum key distribution.	3.1. Operating principle. Bell's inequalities. 3.2. Security and benefits. 3.3. Experimental platforms.
4. Quantum key distribution networks.	4.1. Network architectures. Networks based on trusted nodes and satellite networks. 4.2. Compatibility with optical communication networks. 4.3. Standardization and certification.
5. Quantum random number generators.	5.1. Operating principle. 5.2. Estimation of the quantum entropy. 5.3. Experimental and commercial platforms.

Planning			
	Class hours	Hours outside the classroom	Total hours
Lecturing	18	25	43
Problem solving	4	0	4
Problem and/or exercise solving	0	7	7
Essay	1	10	11
Essay questions exam	2	8	10
*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.			

Methodologies	
	Description
Lecturing	Presentation by the professor of the contents of the subject under study.
Problem solving	Solving problems in the class. Solving problems autonomously by students.

Personalized assistance	
Methodologies	**Description**
Lecturing	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means.
Problem solving	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means.
Tests	**Description**
Essay	Students will be able to attend personalized tutoring sessions in the professor□s office or through telematic means.

Assessment					
	Description	Qualification	Training and Learning Results		
Problem and/or exercise solving	Resolution of problems and/or exercises.	30	A11 A12	B11 B12	C1 C2 C3
Essay	Realization of a project in groups of students guided by the professor.	30	A11 A12	B11 B12	C1 C2 C3

Essay questions exam	Final exam in which all the contents of the subject are evaluated.	40	A11 A12	B11 B12	C1 C2 C3

Other comments on the Evaluation

There will be two evaluation modalities in the ordinary call: continuous evaluation and global evaluation. The continuous evaluation consists of the delivery of exercises solved individually by each student (30%), of a project performed in group and guided by the professor (30%), and a written exam at the end of the course (40%). The overall evaluation will consist of a single written exam at the end of the course. A student will be considered as opting for the overall assessment if they do not submit the set of exercises. The continuous evaluation prevents a final qualification of not presented.

Sources of information

Basic Bibliography

Complementary Bibliography

V. Scarani et al, **The security of practical quantum key distribution**, https://doi.org/10.1103/RevModPhys.81.1301, Rev. Mod. Phys. 81, 1301, American Physical Society, 2009

H.-K. Lo, M. Curty, and K. Tamaki, **Secure quantum key distribution**, https://doi.org/10.1038/nphoton.2014.149, Nat. Photonics 8, 595, Springer Nature, 2014

F. Xu, X. Ma, Q. Zhang, H.-K. Lo, J.-W. Pan, **Secure quantum key distribution with realistic devices**, https://doi.org/10.1103/RevModPhys.92.025002, Rev. Mod. Phys. 92, 025002, American Physical Society, 2020

M. Razavi, **An Introduction to Quantum Communication Networks**, 978-1-6817-4653-1, IOP Concise Physics, 2018

M. Tomamichel, **Quantum Information Processing with Finite Resources**, 978-3-319-21890-8, Springer, 2016

Recommendations

Subjects that it is recommended to have taken before

Fundamentals of quantum communications/V05M198V01105

IDENTIFYING DATA

Quantum optics

Subject	Quantum optics			
Code	V05M198V01112			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/2023 2024/optica-cuantica-19345-18438-3-103743			
General description				

Training and Learning Results

Code	
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
B7	To have knowledge of quantum optics and the role and properties of light and its manipulation in quantum information processing and communications.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A14
	A6
	B18
	B18
	B7
	C1
	C2
	C3
	C18
	C18
	C18
	C18
	D18
	D18
	D18
	D18
	D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

Physical systems for quantum information

Subject	Physical systems for quantum information
Code	V05M198V01113
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica

Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st

Teaching language	
Department	
Coordinator	
Lecturers	
E-mail	
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/sistemas-fisicos-informacion-cuantica-19345-18438-3-103744
General description	

Training and Learning Results

Code	
A4	Know and be able to apply the physical theories inherent to the understanding of systems for quantum information processing, including quantum thermodynamics as well as advanced aspects of magnetism and quantum mechanics.
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
B6	To acquire knowledge about physical systems capable of implementing information processing in quantum degrees of freedom.
B7	To have knowledge of quantum optics and the role and properties of light and its manipulation in quantum information processing and communications.
B10	Knowledge about new solid-state quantum materials, their physical and topological properties.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A4 A6 B6 B7 B10 C1 C18 C2 C3 C18 C18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

Advanced quantum mechanics

Subject	Advanced quantum mechanics			
Code	V05M198V01119			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/mecanica-cuantica-avanzada-19346-18439-3-103753			
General description				

Training and Learning Results

Code	
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B1	To nnow the theoretical foundations of quantum mechanics, the mathematical formalism, the axioms and simpler systems.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A9 A10 B1 B2 C1 C2 C3 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Quantum computing architectures

Subject	Quantum computing architectures			
Code	V05M198V01120			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551022&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
B16	To have knowledge of quantum computer architectures, different platforms and "full stack".
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14 A9 A10 B18 B4 B18 B18 B18 B18 B16 C1 C2 C3 C18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Experimental techniques for quantum information

Subject	Experimental techniques for quantum information			
Code	V05M198V01121			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	1st
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica			
General description				

Training and Learning Results

Code	
A2	Know and acquire competence in experimental techniques for the processing of quantum information: interactions, measurements, oscillations, interference, communication systems, ...
A4	Know and be able to apply the physical theories inherent to the understanding of systems for quantum information processing, including quantum thermodynamics as well as advanced aspects of magnetism and quantum mechanics.
A5	Know and understand the nature of the physical platforms for the processing of quantum information in solid state systems: superconducting systems, cryoscience and quantum materials, including or studying two topological states.
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
B1	To nnow the theoretical foundations of quantum mechanics, the mathematical formalism, the axioms and simpler systems.
B17	To have knowledge of experimental techniques of quantum information and communication. Optical and solid state devices.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A2 A14 A4 A5 A11 B1 B18 B18 B17 C1 C2 C3 C18 C18 D18 D18

Contents

Topic

Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies	
	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Quantum computing and high performance computing

Subject	Quantum computing and high performance computing			
Code	V05M198V01201			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551009&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A8	Know the classical computing algorithms and strategies inspired by quantum computing: tensor networks, product states of matrices, etc.
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B15	To have knowledge of high-level aspects of quantum computing: learning quantum machines, quantum simulators, architectures, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A8 A9 A10 B18 B18 B15 C1 C2 C3 C18 C18 D18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Practical applications of quantum computing

Subject	Practical applications of quantum computing			
Code	V05M198V01202			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551010&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A8	Know the classical computing algorithms and strategies inspired by quantum computing: tensor networks, product states of matrices, etc.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B14	To have knowledge of sets of problems in which quantum computing at its current stage of development can offer an advantage over classical computing: chemistry, biology, optimization, logistics, finance, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A8 A10 B14 C1 C2 C3 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA				
Bug fixing code				
Subject	Bug fixing code			
Code	V05M198V01203			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language	Spanish			
Department				
Coordinator	Fernández Veiga, Manuel			
Lecturers	Fernández Veiga, Manuel			
E-mail	mveiga@det.uvigo.es			
Web	http://quantummastergalicia.es			
General description	Basic theory and applications in computing and communications of quantum error control codes			

Training and Learning Results	
Code	
A13	Know the strategies of quantum cryptography and its feasibility and solvency in the context of the quantum internet, the quantum chain of blocks and secret communications, acquiring a panoramic vision of two actors that will be essential in their deployment.
B13	To be aware of the physical and technical limitations of the implementation of quantum information treatment systems: noise, decoherence, etc., as well as the mitigation or correction strategies that are proposed.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	Training and Learning Results
Ability to understand the construction, analysis and applications of quantum error control codes in communication systems and quantum computers. Knowledge of the main specific codes	A13 B13 C1 C2 C3

Contents	
Topic	
Module 1: Quantum Errors	Overview of quantum errors and their sources. Decoherence and noise in open quantum systems Quantum error models and error types. Digitization of quantum noise. Error operators.
Module 2: Fundamentals of Quantum Error Correction	From classical to quantum error correction The three-qubit error correction code The nine-qubit Shor code Quantum error correction conditions The quantum Hamming bound
Module 3: Constructing quantum codes	Classical linear codes Calderbank-Shor-Steane (CSS) codes
Module 4: Stablizer codes	The stabilizer formalism Measurement in the stabilizer formalism Stabilizer code constructions Quantum circuits for encoding, decoding and correction
Module 5. Topological stabilizer codes	· Z2 chains - Surface codes on a torus · Planar surface codes · Topological quantum error correction

6. Fault-tolerant quantum computing	· Fault tolerance in quantum computing · Fault-tolerant quantum error correction · Coded operations with fault tolerance

Planning

	Class hours	Hours outside the classroom	Total hours
Lecturing	18	23	41
Problem solving	5	15	20
Problem and/or exercise solving	0	12	12
Presentation	2	0	2

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description
Lecturing	The main elements of quantum error codes, their applications and limitations will be presented.
Problem solving	Typical quantum error code design and analysis problems will be solved, in order to learn how to use the methods seen in the lectures.

Personalized assistance

Methodologies	**Description**
Lecturing	Support will be offered during tutoring hours and by e-mail. For contact information, see https://www.uvigo.gal/es/universidad/administracion-personal/pdi/manuel-fernandez-veiga
Problem solving	Support will be offered during tutoring hours and by e-mail. For contact information, see https://www.uvigo.gal/es/universidad/administracion-personal/pdi/manuel-fernandez-veiga
Tests	**Description**
Problem and/or exercise solving	Support will be offered during tutoring hours and by e-mail. For contact information, see https://www.uvigo.gal/es/universidad/administracion-personal/pdi/manuel-fernandez-veiga

Assessment

	Description	Qualification	Training and Learning Results		
Problem and/or exercise solving	Two homework problems sets throughout the course period, 30% each. Individual written submissions.	60	A13	B13	C1 C2 C3
Presentation	Presentation of an essay	40	A13	B13	C1 C2 C3

Other comments on the Evaluation

Two modes of evaluation are offered, continuous evaluation and global evaluation.

The continuous evaluation consists of a written exam at the end of the course (40%) plus two individual exercise resolution tests (30% each). The global evaluation consists of a single exam at the end of the course. A student opts for continuous evaluation if he/she submits any of the exercise resolution tests. Continuous evaluation never results in a grade of "not presented".
In the extraordinary exam the same evaluation system will be used, at the choice of each student.

Sources of information

Basic Bibliography

M. A. Nielsen, I. L. Chuang, **Quantum Computation and Quantum Information**, Cambridge University PRess, 2010

Complementary Bibliography

Giuliano Gadioli La Guardia, **Quantum Error Correction Symmetric, Asymmetric, Synchronizable, and Convolutional Codes**, https://doi.org/10.1007/978-3-030-48551-1, Springer, 2020

Frank Gaitan, **Quantum Error Correction and Fault Tolerant Quantum Computing**, 9780849371998, Routledge - Taylor & Francis, 2013

D. A. Lidar, T. A. Brun, **Quantum Error Correction**, https://doi.org/10.1017/CBO9781139034807, Cambridge University Press, 2013

Recommendations

IDENTIFYING DATA				
Quantum Communications Networks				
Subject	Quantum Communications Networks			
Code	V05M198V01204			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language	Spanish			
Department				
Coordinator	Fernández Vilas, Ana			
Lecturers	Fernández Vilas, Ana González Castaño, Francisco Javier			
E-mail	avilas@uvigo.es			
Web	http://quantummastergalicia.es			
General description	It describes the conceptual basis and main elements of quantum communication networks, as well as their architecture. In addition, this vision is used to review a set of possible applications.			

Training and Learning Results	
Code	
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
A12	Acquire skills for the design and estimation of resources that allow the development of quantum communication channels and networks and distributed computing. Know the state of development and current implementation of quantum networks, and the plans for their expansion.
B11	Knowledge of quantum communications, theoretical principles and experimental implementations, both terrestrial and aerial and via satellite.
B12	To have knowledge about quantum cryptography, its theoretical bases, existing implementations and the challenges they face.
B13	To be aware of the physical and technical limitations of the implementation of quantum information treatment systems: noise, decoherence, etc., as well as the mitigation or correction strategies that are proposed.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	
Expected results from this subject	Training and Learning Results
New	A14 A14 A11 A12 B18 B18 B11 B12 B13 C1 C2 C3

Contents	
Topic	
Introduction	What is QI? Entanglement exchange and distillation. Entanglement distribution.

IQ Elements	Quantum memories. Quantum repeaters. Bell pairs. Memory-based repeaters. Single-photonic repeaters. Entanglement paths.
Architecture of IQ	Architectures. Standardisation initiatives. Networks with trust repeaters. Networks without trust repeaters. Quantum states as resources. Quantum channel and QI capacity.
Applications	Distributed Quantum Computing. Interconnection of QPUs. Neural Networks and QNNs. QKD networks.

Planning

	Class hours	Hours outside the classroom	Total hours
Lecturing	13	30	43
Case studies	4	10	14
Research based methodologies	4	10	14
Essay questions exam	2	0	2
Essay	1	0	1
Case studies	1	0	1

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description
Lecturing	Lecturing
Case studies	Case studies
Research based methodologies	Research based methodologies

Personalized assistance

Methodologies	Description
Lecturing	Personalised tutorials will be given to students who so wish, on any of the theoretical aspects of the subject, in accordance with the modality and timetable of each teacher. Ana Fernández Vilas [https://www.uvigo.gal/es/universidad/administracion-personal/pdi/ana-fernandez-vilas]
Case studies	Personalised tutorials will be provided to students who so wish, on any aspect of the case studies, in accordance with the modality and timetable of each teacher. Ana Fernández Vilas [https://www.uvigo.gal/es/universidad/administracion-personal/pdi/ana-fernandez-vilas]
Research based methodologies	Personalised tutorials will be given to students who so wish, on any of the proposed research topics, in accordance with the modality and timetable of each teacher. Ana Fernández Vilas [https://www.uvigo.gal/es/universidad/administracion-personal/pdi/ana-fernandez-vilas]

Assessment

	Description	Qualification	Training and Learning Results		
Essay questions exam	Essay questions exam	40	A11	B11	C1
			A12	B12	C2
				B13	C3
Essay	Essay	30	A11	B11	C1
			A12	B12	C2
				B13	C3
Case studies	Case studies	30	A11	B11	C1
			A12	B12	C2
				B13	C3

Other comments on the Evaluation

There will be two assessment modalities in the ordinary exam: continuous assessment and global assessment. Continuous assessment consists of the submission of a research project and a case study from among those proposed in the contents. Each one will have a weight of 30% in the final grade, plus a written exam at the end of the course, with a weight of 40%. The overall assessment will consist of a single written exam at the end of the course.

A student will be considered to have opted for the overall assessment if he/she does not hand in the first of the proposed activities. Continuous assessment precludes a final grade of not submitted.

Sources of information

Basic Bibliography

Rodney Van Meter, **Quantum Networking**, https://www.wiley.com/en-gb/Quantum+Networking-p-9781848215375, 1, Wiley, 2014

Riccardo Bassoli, Holger Boche et al, **Quantum Communication Networks. Foundations in Signal Processing, Communications and Networking**, 978-3-030-62937-3, 1, Springer, 2021

Peter P. Rohde, **The Quantum Internet: The Second Quantum Revolution**, https://doi.org/10.1017/9781108868815, 1, Cambridge University Press, 2021

Mohsen Razavi, **. An Introduction to Quantum Communications Networks Or, how shall we communicate in the quantum era?**, https://iopscience.iop.org/book/mono/978-1-6817-4653-1, 1, Morgan & Claypool Publishers, 2018

Ivan Djordjevic, **Quantum Communication, Quantum Networks, and Quantum Sensing**, 9780128229422, 1, Elsevier, 2022

Miralem Mehic , Stefan Rass , Peppino Fazio , Miroslav Voznak, **Quantum Key Distribution Networks: A Quality of Service Perspective**, https://doi.org/10.1007/978-3-031-06608-5, 1, Springer, 2022

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Quantum materials

Subject	Quantum materials			
Code	V05M198V01205			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/materiais-cuanticos-19345-18438-3-103745			
General description				

Training and Learning Results

Code	
A4	Know and be able to apply the physical theories inherent to the understanding of systems for quantum information processing, including quantum thermodynamics as well as advanced aspects of magnetism and quantum mechanics.
A5	Know and understand the nature of the physical platforms for the processing of quantum information in solid state systems: superconducting systems, cryoscience and quantum materials, including or studying two topological states.
B6	To acquire knowledge about physical systems capable of implementing information processing in quantum degrees of freedom.
B10	Knowledge about new solid-state quantum materials, their physical and topological properties.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A4 A5 B6 B10 C1 C2 C3

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Open systems and quantum thermodynamics

Subject	Open systems and quantum thermodynamics			
Code	V05M198V01206			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/sistemas-abertos-termodinamica-cuantica-19345-18438-3-103746			
General description				

Training and Learning Results

Code	
A4	Know and be able to apply the physical theories inherent to the understanding of systems for quantum information processing, including quantum thermodynamics as well as advanced aspects of magnetism and quantum mechanics.
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
B1	To nnow the theoretical foundations of quantum mechanics, the mathematical formalism, the axioms and simpler systems.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14 A14 A14 A14 A4 A14 A6 B1 B2 B18 C1 C2 C3 C18 D18 D18 D18 D18 D18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies	
	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

Metrology and quantum sensors

Subject	Metrology and quantum sensors			
Code	V05M198V01207			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language	Galician			
Department				
Coordinator	Paredes Galán, Ángel			
Lecturers	Paredes Galán, Ángel			
E-mail	angel.paredes@uvigo.es			
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/metroloxia-sensores-cuanticos-19345-18438-3-103747			
General description				

Training and Learning Results

Code	
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
B5	To have knowledge of quantum information theory, universal limitations, and their implications for computing, communications, and metrology.
B7	To have knowledge of quantum optics and the role and properties of light and its manipulation in quantum information processing and communications.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A3 B5 B7 C1 C2 C3

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Numerical methods in quantum computing

Subject	Numerical methods in quantum computing			
Code	V05M198V01208			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551025&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
B14	To have knowledge of sets of problems in which quantum computing at its current stage of development can offer an advantage over classical computing: chemistry, biology, optimization, logistics, finance, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14 A14 A14 A14 A14 A9 A10 B4 B14 C1 C2 C18 C3 C18 D18 D18

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Introduction to quantum simulation

Subject	Introduction to quantum simulation			
Code	V05M198V01209			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web				
General description				

Training and Learning Results

Code	
A3	Understanding and knowledge of the fundamentals of Quantum Information Theory, as well as two basic aspects of two four types of quantum technologies: computing, communications, metrology, simulation.
A8	Know the classical computing algorithms and strategies inspired by quantum computing: tensor networks, product states of matrices, etc.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
B14	To have knowledge of sets of problems in which quantum computing at its current stage of development can offer an advantage over classical computing: chemistry, biology, optimization, logistics, finance, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14 A14 A3 A14 A8 B18 B4 B18 B18 B18 B14 C1 C2 C3

Contents

Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA

Science and technology of superconductivity

Subject	Science and technology of superconductivity			
Code	V05M198V01210			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/ciencia-tecnoloxia-supercondutividade-19346-18439-3-103748			
General description				

Training and Learning Results

Code	
A4	Know and be able to apply the physical theories inherent to the understanding of systems for quantum information processing, including quantum thermodynamics as well as advanced aspects of magnetism and quantum mechanics.
A5	Know and understand the nature of the physical platforms for the processing of quantum information in solid state systems: superconducting systems, cryoscience and quantum materials, including or studying two topological states.
B6	To acquire knowledge about physical systems capable of implementing information processing in quantum degrees of freedom.
B10	Knowledge about new solid-state quantum materials, their physical and topological properties.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A4 A5 B6 B10 C1 C2 C3 C18 C18 C18 D18 D18 D18 D18 D18 D18 D18

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Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

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Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA				
Semiconductor photonics				
Subject	Semiconductor photonics			
Code	V05M198V01211			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/fotonica-semicondutores-19346-18439-3-103750			
General description				

Training and Learning Results	
Code	
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
B6	To acquire knowledge about physical systems capable of implementing information processing in quantum degrees of freedom.
B7	To have knowledge of quantum optics and the role and properties of light and its manipulation in quantum information processing and communications.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	
Expected results from this subject	Training and Learning Results
New	A6 B6 B7 C1 C2 C3 C18 C18 C18 D18 D18 D18 D18 D18 D18 D18

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Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies
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Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

Rule-based quantum systems

Subject	Rule-based quantum systems			
Code	V05M198V01212			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://guiadocente.udc.es/guia_docent/index.php?centre=614&ensenyament=614551&assignatura=614551029&any_academic=2023_24&any_academic=2023_24			
General description				

Training and Learning Results

Code	
A9	Know and know how to apply advanced aspects of quantum computing: quantum learning, efficient quantum architecture, mode of operation of two quantum accelerators, high-performance computing, quantum systems based on rules and applications to numerical calculation.
B3	To know the physical bases that allow encoding and processing information. Understanding of the new rules that Quantum Mechanics imposes for its processing.
B4	To have knowledge of quantum computing, algorithms, circuits, its programming in different languages and accessible platforms.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A9
	B18
	B3
	B4
	B18
	B18
	C1
	C2
	C3
	C18
	C18
	D18
	D18
	D18
	D18
	D18

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Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

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Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA				
Quantum Communications Laboratory				
Subject	Quantum Communications Laboratory			
Code	V05M198V01213			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web				
General description				

Training and Learning Results	
Code	
A2	Know and acquire competence in experimental techniques for the processing of quantum information: interactions, measurements, oscillations, interference, communication systems, ...
A6	Know and understand the nature of the physical platforms for the processing of quantum information in photonic systems: quantum optics, integrated optical systems, opto-atomic systems, detection and measurement systems, semiconductor photonics.
B1	To nnow the theoretical foundations of quantum mechanics, the mathematical formalism, the axioms and simpler systems.
B2	To acquire knowledge about quantum systems with many degrees of freedom as a means of storing and processing information.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	
Expected results from this subject	Training and Learning Results
New	A2 A6 B18 B1 B2 B18 B18 C1 C2 C3 C18 D18 D18 D18 D18 D18 D18 D18 D18 D18 D18 D18 D18 D18

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Planning			
	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

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Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

External practices I

Subject	External practices I			
Code	V05M198V01214			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Mandatory	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/practicas-externas-19347-18440-2-103737			
General description				

Training and Learning Results

Code	
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
A13	Know the strategies of quantum cryptography and its feasibility and solvency in the context of the quantum internet, the quantum chain of blocks and secret communications, acquiring a panoramic vision of two actors that will be essential in their deployment.
B14	To have knowledge of sets of problems in which quantum computing at its current stage of development can offer an advantage over classical computing: chemistry, biology, optimization, logistics, finance, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A10
	A13
	B14
	C1
	C2
	C3
	C18
	C18
	C18
	D18
	D18
	D18
	D18
	D18
	D18

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Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment		
Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information
Basic Bibliography
Complementary Bibliography

Recommendations

IDENTIFYING DATA

External practices II

Subject	External practices II			
Code	V05M198V01215			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language				
Department				
Coordinator				
Lecturers				
E-mail				
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/20232024/practicas-externas-ii-19346-18439-3-103738			
General description				

Training and Learning Results

Code	
A10	Know scenarios of practical application of quantum computing in problems of scientific, technological and financial interest. Identify domains that exhibit quantum advantage. Know the institutions and companies that are actors in quantum computing, acquiring a perspective of the agenda that is reasonable to expect in the coming years.
A13	Know the strategies of quantum cryptography and its feasibility and solvency in the context of the quantum internet, the quantum chain of blocks and secret communications, acquiring a panoramic vision of two actors that will be essential in their deployment.
B14	To have knowledge of sets of problems in which quantum computing at its current stage of development can offer an advantage over classical computing: chemistry, biology, optimization, logistics, finance, etc.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A14
	A14
	A14
	A10
	A13
	B18
	B14
	C1
	C18
	C2
	C3
	C18

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Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

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Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations

IDENTIFYING DATA				
Quantum communications via satellite				
Subject	Quantum communications via satellite			
Code	V05M198V01216			
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica			
Descriptors	ECTS Credits	Choose	Year	Quadmester
	3	Optional	1st	2nd
Teaching language	#EnglishFriendly			
Department				
Coordinator	Mosquera Nartallo, Carlos			
Lecturers	Aguado Agelet, Fernando Antonio Mosquera Nartallo, Carlos			
E-mail	mosquera@gts.uvigo.es			
Web	http://moovi.uvigo.gal			
General description	This course covers the technological framework of quantum communications based on satellite links, with special emphasis on the optical channel and all the involved subsystems.			

Training and Learning Results	
Code	
A11	Acquiring a solid foundation on quantum theory gives information on its application in quantum communications, as well as on the technology of two photonic devices used in quantum communications, both terrestrial and aerial and via satellite.
A12	Acquire skills for the design and estimation of resources that allow the development of quantum communication channels and networks and distributed computing. Know the state of development and current implementation of quantum networks, and the plans for their expansion.
A13	Know the strategies of quantum cryptography and its feasibility and solvency in the context of the quantum internet, the quantum chain of blocks and secret communications, acquiring a panoramic vision of two actors that will be essential in their deployment.
B11	Knowledge of quantum communications, theoretical principles and experimental implementations, both terrestrial and aerial and via satellite.
B12	To have knowledge about quantum cryptography, its theoretical bases, existing implementations and the challenges they face.
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject	
Expected results from this subject	Training and Learning Results
New	A11 A12 B11 B12 C1 C2
New	A13 B11 C3

Contents	
Topic	
1.Introduction to satellite quantum communications	1.1 Introduction to the architecture of a space system 1.2 Orbits 1.3 Engineering of systems and space standards
2. Architecture of space systems for quantum communications	2.1 Main architectures for quantum communications 2.2 Integration with the quantum ground network

3. Optical communications through satellite links	3.1 Principles of signal transmission 3.2 Characterisation of the atmospheric channel 3.3 Computation of link budget
4. Subsystems of satellite quantum communications	4.1 Transmitters and optical receptors 4.2 Optical elements 4.3 Telescopes 4.4 Adaptive optics 4.5 Systems for pointing, acquisition and tracking
5. Examples of QKD systems	5.1 Main experimental platforms for satellite QKD 5.2 Use cases

Planning

	Class hours	Hours outside the classroom	Total hours
Lecturing	16	32	48
Problem solving	4	8	12
Practices through ICT	5	8	13
Objective questions exam	0	2	2

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Methodologies

	Description
Lecturing	The main elements of a satellite communication system will be presented, with focus on the architecture, channel and subsystems that are specific of the optical and quantum communication.
Problem solving	Different problems will be proposed that entail the use of mathematical software and/or the search for information on specific aspects of space quantum communication systems.
Practices through ICT	Different aspects of satellite communications will be addressed by making use of specific simulation software.

Personalized assistance

Methodologies	Description
Lecturing	Support will be offered during office hours and by e-mail. For contact information, go to https://www.uvigo.gal/en/university/administration-staff/pdi/carlos-mosquera-nartallo
Problem solving	Support will be offered during office hours and by e-mail. For contact information, go to https://www.uvigo.gal/en/university/administration-staff/pdi/carlos-mosquera-nartallo
Practices through ICT	Support will be offered during office hours and by e-mail. For contact information, go to https://www.uvigo.gal/en/university/administration-staff/pdi/carlos-mosquera-nartallo

Assessment

	Description	Qualification	Training and Learning Results		
Problem solving	Weekly homework will be proposed, and evaluated if delivered within the allocated deadline.	40			C1 C2 C3
Practices through ICT	A report must be turned in relation to those practical tasks which make use of specific software for some aspects of satellite quantum communication systems.	40	A12		
Objective questions exam	Final exam with short questions and exercises	20	A11 A13	B11 B12	

Other comments on the Evaluation

The final exam will be graded for the 100% of the course in those cases for which no deliverables have been turned in for grading purposes. Similarly, the grade of the course will be based exclusively on the final exam if the student opts out of the continuous evaluation track within the first month of course activities.

Sources of information

Basic Bibliography

Complementary Bibliography

Uysal, M and Capsoni, C and Ghassemlooy, Z and Boucouvalas, A and Udvary, E, **Optical wireless communications - an emerging technology**, Springer, 2016

https://ecss.nl/, **European Cooperation for Space Standardization**,

http://www.sme-smad.com/, **New SMAD (Libro de referencia en misiones espaciales)**,
Howard D. Curtis, **Orbital Mechanics for Engineering Students**, 978-0-08-097747-8, Elsevier, 2014

Recommendations

IDENTIFYING DATA

Final Master's Project

Subject	Final Master's Project
Code	V05M198V01217
Study programme	(*)Máster Universitario en Ciencia e tecnoloxías de información cuántica

Descriptors	ECTS Credits	Choose	Year	Quadmester
	15	Mandatory	1st	2nd

Teaching language	
Department	
Coordinator	
Lecturers	
E-mail	
Web	http://www.usc.gal/gl/estudos/masteres/ciencias/master-universitario-ciencia-tecnoloxias-informacion-cuantica/2023 2024/traballo-master-19347-18440-2-103735
General description	

Training and Learning Results

Code	
C1	To analyze and break down a complex concept, examine each part and see how they fit together
C2	To classify and identify types or groups, showing how each category is different from the others
C3	To compare and contrast and point out similarities and differences between two or more topics or concepts

Expected results from this subject

Expected results from this subject	Training and Learning Results
New	A14
	A14
	A14
	A14
	B18
	B18
	B18
	B18
	B18
	C1
	C2
	C3

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Topic

Planning

	Class hours	Hours outside the classroom	Total hours

*The information in the planning table is for guidance only and does not take into account the heterogeneity of the students.

Methodologies

	Description

Personalized assistance

Assessment

Description	Qualification	Training and Learning Results

Other comments on the Evaluation

Sources of information

Basic Bibliography

Complementary Bibliography

Recommendations