COURSE OUTLINE

(1) GENERAL INFORMATION

SCHOOL	SCHOOL OF APPLIED MATHEMATICAL AND PHYSICAL SCIENCES		
DEPARTMENT	SCHOOL OF APPLIED MATHEMATICAL AND PHYSICAL SCIENCES		
LEVEL OF STUDIES	POSTGRADUATE		
MSc PROGRAM	MICROSYSTEMS AND NANODEVICES		
COURSE CODE	**9969**	**SEMESTER**	**2**
COURSE TITLE	QUANTUM TECHNOLOGIES		

INDEPENDENT TEACHING ACTIVITIES *In cases where credits are awarded to discrete parts of the course (e.g., Lectures, Laboratory Exercises, etc.), specify them. If credits are awarded as a whole, specify weekly teaching hours and total credits.*	**WEEKLY TEACHING HOURS**	**ECTS**
Lectures – Exercises	3	6 ECTS
Laboratory	0	
Assignments	0	
(Additional rows may be added if necessary. Detailed descriptions of teaching organization and methods are provided in section (d).)		

COURSE TYPE *general background, specialized background, specialization, skill development*	SPECIALIZATION OF KNOWLEDGE
PREREQUISITES:	QUANTUM MECHANICS, OPTICS
LANGUAGE OF INSTRUCTION and EXAMINATION:	GREEK OR ENGLISH
COURSE AVAILABLE TO ERASMUS STUDENTS	NO
COURSE WEBSITE (URL)	https://helios.ntua.gr/course/view.php?id=3015

(2) LEARNING OUTCOMES

Learning Outcomes

This section describes the learning outcomes of the course, specifying the knowledge, skills, and competencies at the appropriate level that students will acquire upon successful completion of the course.

Refer to Appendix A:

- *Description of the Level of Learning Outcomes for each cycle of studies according to the European Higher Education Area Qualifications Framework*
- *Descriptive Indicators for Levels 6, 7, & 8 of the European Qualifications Framework for Lifelong Learning and Appendix B.*
- *Concise Guide to Writing Learning Outcomes*

Knowledge:

Upon successful completion of the course, students will gain a comprehensive understanding of the fundamental principles of quantum technologies and quantum optics. This includes mastering canonical quantization, the quantum harmonic oscillator, and the quantization of light. They will explore Fock states, single-photon states, photon entanglement, and the behavior of individual photons in beam splitters and interferometers. Additionally, students will examine coherent and incoherent states, multimode quantized radiation, and the interaction between light and matter, along with its applications in quantum technologies. The course delves into advanced phenomena such as the Heisenberg limit, NOON states, and their significance in quantum lithography and the Hong–Ou–Mandel effect. Students will also explore quantum imaging through correlations and become familiar with the principles of atomic clocks, atomic traps (including the Paul trap, magneto-optical trap, and Sisyphus cooling), and optical tweezers. Furthermore, the curriculum covers the principles of quantum cryptography (QKD) and related protocols such as BB84, E91, B92, Six-State, Decoy State, and SARG04. Students will learn about entanglement protocols, quantum repeaters, quantum networks, and the quantum internet. Finally, through hands-on laboratory exercises, students will gain practical experience in implementing quantum algorithms (e.g., Deutsch, VQE) on NMR quantum computers and will become proficient in simulating quantum cryptography using Qiskit.

Skills:

- Through participation in the course, students will develop:
- The ability to work effectively both independently and as part of a team, facilitated by collaborative assignments.
- Proficiency in evaluating, analyzing, and synthesizing data and information within a rapidly advancing field that integrates scientific research with technological applications.
- A thorough and systematic understanding of complex phenomena and processes associated with quantum technologies, with a particular emphasis on photonic devices for their implementation.

General Competencies

Considering the general competencies that graduates are expected to acquire (as stated in the Diploma Supplement), which competencies does this course aim to develop?

Data search, analysis, and synthesis, utilizing necessary technologies
Adaptability to new situations
Decision-making
Independent work (primarily through assignments completed at home)
Teamwork
Working in an international environment
Working in an interdisciplinary environment
Generation of new research ideas
Project design and management
Respect for diversity and multiculturalism
Respect for the natural environment
Exhibiting social, professional, and ethical responsibility and sensitivity to gender issues
Critical and self-critical thinking
Promotion of free, creative, and inductive thinking

Competencies:

- Investigation, processing, and integration of data and information using appropriate technologies.
- Flexibility and adaptability to new conditions.
- Ability to work independently.
- Collaboration and effective teamwork.

(3) COURSE CONTENT

- Canonical quantization / Quantum harmonic oscillator
- Canonical quantization of light
- Fock states / Vacuum states
- Single-photon states
- Behavior of Individual Photons at Beam Splitters and in Interferometers
- Quantum entanglement with photons
- Multimode quantized radiation
- Coherent states
- Coherent states in beam splitters and interferometers
- Incoherent states
- Light-matter interaction
- Heisenberg limit, NOON states, super-sensitivity, super-resolution, quantum lithography, Hong–Ou–Mandel effect
- Quantum imaging, correlated photon imaging, ghost imaging, quantum illumination, quantum radar, measurement without interaction
- Atomic clocks, quartz crystals, Cs atoms, Stern–Gerlach apparatus, thermal atomic clocks, applications of atomic clocks
- Cooling and trapping of atoms, Paul trap, laser cooling, magneto-optical trap, Sisyphus cooling, dipole trap, optical tweezers, and optical lattice
- Quantum cryptography (QKD), discrete QKD protocols (BB84, E91, B92 Two-State, Six-State, Decoy State, SARG04), continuous QKD protocols Quantum cryptography (QKD), discrete QKD protocols (BB84, E91, B92 Two-State, Six-State, Decoy State, SARG04), continuous QKD protocols

- Entanglement-based protocols, quantum repeaters, quantum networks, quantum internet, and entanglement-based protocols, quantum repeaters, quantum networks, quantum internet, and society implications

  Laboratory Exercises
- A1: Implementation of the Deutsch quantum algorithm on SpinQ NMR Quantum Computers
- A2: Implementation of a Variational Quantum Eigensolver (VQE) Algorithm on NMR Quantum Computers
- A3: Simulation of Quantum Key Distribution (QKD) Protocols Using the Qiskit Programming Language.

(4) TEACHING AND LEARNING METHODS - ASSESSMENT

TEACHING METHOD *In person, Distance Learning etc.*	Face to face
USE OF INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT) *Use of Information and Communication Technologies (ICT) in Lecturing, Laboratory Training, Communication with Students*	Notes, Homework Assignments (assignments from the lecturer and submissions from the students). Presentations.
ORGANIZATION OF TEACHING *A detailed description of the teaching methods and approaches used in the course, which may include:* *Lectures, Seminars, Laboratory Exercises, Fieldwork, Study and Analysis of Bibliography, Tutorials, Internships, Clinical Exercises, Art Workshops, Interactive Teaching, Educational Visits, Project Development, Report Writing/Assignments, Artistic Creation.* *The student's study hours for each learning activity, as well as hours of independent study, are outlined in accordance with ECTS principles*	see table below

Activity	*Semester Workload*
Lectures	13x3=39 hours
Study	13x3=39 hours
Home Assignments/Exercises	10x3=30 hours
Laboratory	3X3=9 hours
Completion/Presentation of Project	23 hours
Educational Visits	0
Examinations	
Total Course Load	140

STUDENT ASSESSMENT *Description of the Assessment Process* *Language of Assessment, Assessment Methods, Formative / Summative Assessment Methods, Multiple-choice tests, Short-answer questions, Essay-style questions, Problem-solving exercises, Written assignments, Reports, Oral examinations, Public presentations, Laboratory work, Clinical patient examinations, Artistic interpretations, Other methods, as appropriate* *The assessment criteria are clearly defined and provided to students, ensuring transparency in the evaluation process. These criteria are accessible through the course's online platform where students can review them at any time*	**Language of Assessment**: Greek **Problem-solving from Exercise Series and Laboratory Exercises**: 20% **Final Oral Examination**: 40% **Completion/Presentation of Project**: 40% Explicit mention of these assessment criteria will be available on the Helios platform

(5) RECOMMENDED BIBLIOGRAPHY

R. LaPierre, Getting Started in Quantum Optics (Springer)

P. Lambropoulos and D. Petrosyan, *Fundamentals of Quantum Optics and Quantum Information*, Springer.

M. Fox, Κβαντική Οπτική (Πανεπιστημιακές Εκδόσεις Κρήτης)

David S. Simon, Gregg Jaeger, Alexander V. Sergienko, Quantum Metrology, Imaging, and Communication (Springer)

Guanru Feng, et al, Quantum computing: principles and applications http://arxiv.org/abs/2310.09386