POZNAN UNIVERSITY OF TECHNOLOGY

EUROPEAN CREDIT TRANSFER AND ACCUMULATION SYSTEM (ECTS)

COURSE DESCRIPTION CARD - SYLLABUS

Course name

Fundamentals of Quantum Engineering [S1FT2>PIK]

Course

Field of study

Technical Physics

Year/Semester

3/5

Area of study (specialization)

–

Profile of study

general academic

Level of study

first-cycle

Course offered in

Polish

Form of study

full-time

Requirements

compulsory

Number of hours

Lecture

30

Laboratory classes

15

Other (e.g. online)

0

Tutorials

15

Projects/seminars

0

Number of credit points

6,00

Coordinators

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Lecturers

Prerequisites

Knowledge of experimental physics, quantum physics, atomic physics, optical constructions, higher mathematics basics, analytical and symbolic methods. The ability to solve simple physical problems based on acquired knowledge, perform simple physical measurements, basic operation of an oscilloscope, function generator, and universal electronic meters, proficiency in using symbolic algebra software. Understanding the need to expand one's competencies, readiness for teamwork.

Course objective

1. To provide students with basic knowledge regarding the analysis and engineering of quantum states of isolated quantum objects, enabling understanding and application of simple functional modules developed in particularly quantum information technologies. 2. To develop students' algorithmic analysis skills for planning and executing simple quantum measurements, processes, and experiments, as well as configuring and using simple functional modules for these processes within the scope defined by the program content. 3. To foster students' skills in self-education and professional team collaboration.

Course-related learning outcomes

Knowledge:

As a result of the course, the student will gain knowledge in the following areas:
1. Understanding of basic quantum phenomena, especially in the field of quantum optics used in quantum engineering.
2. The ability to define basic types of quantum system states important in quantum engineering based on their mathematical description; distinguishing between pure and mixed states, entangled and separable states; coherent states and Fock states.
3. Characterization of selected implementations and applications of quantum engineering.

Skills:
As a result of the course, the student will master the following skills:
1. Description of a qubit quantum state and a two-qubit system, and calculating the probability of outcomes for specific quantum measurement projections.
2. Execution of the quantum state tomography procedure of a qubit implemented in polarization states of light and analysis of obtained results.
3. Performing simple calculations related to transformations of single qubits and their simple systems.
4. Conducting transformations of a quantum state of a qubit implemented in polarization states of light using linear elements (retarders, polarizers) and optical modules.
5. Analysis of simple quantum circuits and determining subsequent quantum states assumed by a qubit system after transformation by the functional modules of a quantum circuit.

Social competences:
As a result of the course, the student will develop the following social competences:
1. The ability to work independently and as part of a team, demonstrating responsibility for the reliability of the results of one's own work and the team's work.
2. Professional behavior with responsibility for personal and team safety.

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

1. Lecture:
The form and components of the evaluation (percentage share): Written exam - multiple-choice questions and open questions (80%), oral exam (20%).
Grading: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.
2. Exercises:
The form and components of the evaluation (percentage share): Continuous tests during exercises (100%).
Grading: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.
3. Laboratory:
The form and components of the evaluation (percentage share): Continuous assessment of laboratory exercise execution documented in a lab notebook (60%), summary test (30%), report in the form of a manuscript from a specified exercise (10%).
Grading: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.

Programme content

none

Course topics

1. Tomography and engineering of single qubit states.
a. Unified description and tomography of a quantum state (pure and mixed) of a single qubit.
b. Transformation of single qubit states - elementary one-qubit quantum gates.
c. Engineering of single qubit dynamics in a semiclassical approach - Rabi oscillations.
d. L: Transformation of polarization states of light.
e. L: Tomography of polarization states of light.
2. Two-qubit systems and simple quantum circuits.
a. Description of two-qubit system states. Bell inequality - operations and entanglement in quantum systems.
b. Engineering dynamics and transformations of two-qubit system states. Two-qubit quantum gates. No-cloning theorem.

c. Synthesis of unitary transformations. Simple quantum circuits and quantum state teleportation.
d. L: Synthesis of arbitrary polarization states of light - combination of rotation transformation operations.
3. Tools and implementations.
a. Quantum electromagnetic fields in a resonant cavity. Detection and statistical characterization of light in Fock states and coherent states
b. Isolated quantum systems and their observation - Paul trap.
c. Jaynes-Cummings model of interaction of a two-level system with electromagnetic field.
d. L: Calibration of a photodetector.
e. L: Detection of single photons using an avalanche photodiode.
4. Applications (Part 1) - Elements of Quantum Computing:
a. Quantum random number generator. Basics of quantum key distribution.
b. Quantum processor - requirements and applications. Implementation examples.
c. Analysis of simple quantum algorithms.
d. L: Quantum interference - the quantum eraser phenomenon in the Mach-Zehnder interferometer.
e. L: Investigation of a quantum random number generator.
5. Applications (Part 2) - Elements of Quantum Metrology:
a. Non-destructive measurements of quantum states.
b. Quantum sensors and detectors based on single isolated structures. Ramsey interferometry.
c. Basics of entanglement-enhanced interferometry; NOON states.
d. L: Non-destructive measurement - quantum Zeno effect.
(L - Laboratory)

Teaching methods

1. Lecture: Multimedia presentations supplemented with examples provided on the board.
2. Exercises: Individual and group problem solving; guided and independent case analysis, e.g., concerning quantum circuits.
3. Laboratory: Conducting physical experiments, implementation of measurement protocols, operation of measurement instruments and devices, analysis and reporting of measurement results, work in small experimental teams.

Bibliography

Basic:
1. Bernard Zygelman, A First Introduction to Quantum Computing and Information, Springer 2018, pozycja dostępna w formie e-booka poprzez E-Zasoby Biblioteki Politechniki Poznańskiej
2. Abraham Asfaw, Luciano Bello, Yael Ben-Haim, Sergey Bravyi, Nicholas Bronn, Lauren Capelluto, Almudena Carrera Vazquez, Jack Ceroni, Richard Chen, Albert Frisch, Jay Gambetta, Shelly Garion, Leron Gil, Salvador De La Puente Gonzalez, Francis Harkins, Takashi Imamichi, David McKay, Antonio Mezzacapo, Zlatko Minev, Ramis Movassagh, Giacomo Nannicni, Paul Nation, Anna Phan, Marco Pistoia, Arthur Rattew, Joachim Schaefer, Javad Shabani, John Smolin, Kristan Temme, Madeleine Tod, Stephen Wood, James Wootton, "Learn Quantum Computation Using Qiskit", 2020, http://community.qiskit.org/textbook;
3. Christopher C. Gerry, Peter L. Knight , Wstęp do optyki kwantowej, Wydawnictwo Naukowe PWN 20071. M. Le Bellac, Wstęp do informatyki kwantowej, Wydawnictwo Naukowe PWN 2011, pozycja dostępna w formie e-booka poprzez E-Zasoby Biblioteki Politechniki Poznańskiej

Additional:
1. Michel Le Bellac, Wstęp do informatyki kwantowej, Wydawnictwo Naukowe PWN 2011, pozycja dostępna w formie e-booka poprzez E-Zasoby Biblioteki Politechniki Poznańskiej
2. Mark Beck, Quantum mechanics : theory and experiment, Oxford University Press 2012
3. Marek Sawerwain, Joanna Wiśniewska, Informatyka kwantowa : wybrane obwody i algorytmy, Wydawnictwo Naukowe PWN 2015

Breakdown of average student's workload

	Hours	ECTS
Total workload	150	6,00
Classes requiring direct contact with the teacher	62	2,50
Student's own work (literature studies, preparation for laboratory classes/ tutorials, preparation for tests/exam, project preparation)	88	3,50