POZNAN UNIVERSITY OF TECHNOLOGY

EUROPEAN CREDIT TRANSFER AND ACCUMULATION SYSTEM (ECTS)

COURSE DESCRIPTION CARD - SYLLABUS

Course name
Fundamentals of quantum engineering [S1FT1>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

5,00

Coordinators

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Lecturers

Prerequisites

Knowledge of experimental physics, quantum physics, atomic physics, optical structures, the basics of higher mathematics, analytical and symbolic methods. The ability to solve simple physical problems based on the possessed knowledge. Performing simple physical measurements, basic operation of an oscilloscope, function generator and universal electronic meters. Ability to use symbolic algebra programs. Understanding the necessity of expanding one"s competences, readiness to cooperate within teams.

Course objective

1. Provide students with basic knowledge on the analysis and engineering of quantum states of isolated quantum objects, allowing them to understand the operation and use simple functional modules of the developed techniques, especially quantum-information technology. 2. Developing students" skills in algorithmic analysis, planning and implementing simple quantum measurements, processes and experiments as well as configuring and using simple functional modules to implement these processes, within the scope defined by the programme content. 3. Developing students" skills for self-education and professional teamwork.

Course-related learning outcomes

Knowledge:
as a result of the course, the student will acquire knowledge in the following scope:
1. knowledge of basic quantum phenomena, in particular in the field of quantum optics, used in quantum engineering;
2.defining the basic types of states of quantum systems, important in quantum engineering, based on their mathematical description; distinguish between pure and mixed, entangled and separable states; coherent 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 the quantum state of a qubit and a system of two qubits, and calculating the probability of the results of specific quantum projective measurements;
2. performing the procedure of quantum qubit state tomography in implementation on the polarization states of light and analysis of the obtained results;
3. performing simple calculations regarding the transformation of states of single qubits and their simple systems;
4. transforming the quantum state of a qubit, in implementation on polarization states of light, using linear elements (retarders, polarizers) and optical modules;
5. the analysis of simple quantum circuits and the determination of subsequent quantum states assumed by the qubit system after transformation by the functional modules of the quantum circuit.

Social competences:
as a result of the course, the student will develop the following social competences:
1. independent and team ethical work, demonstrating responsibility for the reliability of the results of his own and team work;
2. professional behavior with responsibility for their own and team safety.

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

Learning outcomes presented above are verified as follows:
1. Lecture (learning outcome: W01, W02, W03, U03):
- form and components (percentage) of assessment: written exam - test and problem tasks (80%), oral exam (20%) ;
- assessment criteria /grade: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.
2. Classes(learning outcome: U01, U03, K01):
- form and components (percentage) of assessment: current tests during classes (100%);
- assessment criteria /grade: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.
3. Laboratory exercises (learning outcome: U02, U04, K01, K02):
- form and components (percentage) of assessment: current assessment of the implementation of laboratory exercises documented in a laboratory notebook (60%); manuscript report (30%); report in manuscript form for a specified exercise (10%)
- assessment criteria /grade: 96% - /5,0; 86%- 95% /4,5; 76%-85% /4; 66 -75% /3,5; 50%-65.0% /3; < 50% /2.

Programme content

1. Tomography and state engineering of a single qubit.
a.Unified description and tomography of the quantum state (pure and mixed) of a single quantum qubit.
b.Transformation of rotation of single qubit states - elementary one-qubit quantum gates.
c. Dynamics engineering of a single qubit in the semi-classical approach - Rabi oscillations.
d. L: Rotation 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 the states of two-qubit systems. Bell"s inequality - operations and entanglement in quantum systems.
b. Dynamics engineering and state transformations of two-qubit systems. Two-qubit quantum gates.

The non-cloning theorem.
c. Synthesis of unitary transformations. Simple quantum circuits and teleportation of quantum states.
d. L: Synthesis of arbitrary polarization states of light -composition of rotation transformation operations.
3.Tools and implementations.
a. Quantum electromagnetic fields in a resonant cavity. Detection and statistical characterization of light in Fock and coherent states.
b.Isolated quantum systems and their observation - Paul ion trap
c. Jaynes-Cummings model of the interaction of a two-level system with an electromagnetic field.
d. L:Photodetector calibration.
e. L: Detection of single photons with an avalanche photodiode.
4. Applications (part 1.) - elements of quantum computing.
a. Quantum random number generator. Fundamentals of the quantum encryption key distribution.
b. Quantum processor - requirements and applications. Implementation examples.
c. Analysis of simple quantum algorithms.
d. L: Quantum interference - the phenomenon of a quantum eraser in a 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. Fundamentals of quantum entanglement enhanced interferometry, NOON states.
d. L: Quantum non-destructive measurement - Zeno quantum effect.
(L-Laboratory exercises)

Teaching methods

1. Lecture: multimedia presentation supplemented with examples given on the blackboard.
2. Classes: individual and team problem solving; guided and self-directed case studies, e.g. on quantum circuits.
3. Laboratory exercises: conducting physical experiments, implementation of measurement protocols; operation of measuring 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, the item is available in the form of an e-book through the E-resources of the Library of the Poznań University of Technology
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 2007, the item is available in the form of an e-book through the E-resources of the Library of the Poznań University of Technology
Additional
1. Michel Le Bellac, Wstęp do informatyki kwantowej, Wydawnictwo Naukowe PWN 2011, the item is available in the form of an e-book through the E-resources of the Library of the Poznań University of Technology
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	132	5,00
Classes requiring direct contact with the teacher	72	3,00
Student's own work (literature studies, preparation for laboratory classes/ tutorials, preparation for tests/exam, project preparation)	90	3,00