# COURSE DESCRIPTION CARD - SYLLABUS

Course name
Quantum computing [S1ETI1>IK]

## Course

Field of study
Education in Technology and Informatics

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
15

Laboratory classes
15

Other (e.g. online)
0

Tutorials
30

Projects/seminars
0

## Number of credit points

5,00

## Coordinators

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## Lecturers

## Prerequisites

Fundamental knowledge of quantum physics and linear algebra. Ability of performing elementary operations in linear algebra, ability of obtaining information from indicated sources. Understanding of necessity of extending one's own competences, readiness to take up cooperation within a team.

## Course objective

1. Transferring to students the fundamental knowledge in quantum computing, within the frame described in program contents. 2. Developing the skills of solving simple problems on the basis of the knowledge acquired, as well as the ability of planning and realization of simple quantum experiments, of configuring and use of simple functional modules for realization of these experiments. 3. Developing the abilities of self-education and team work.

## Course-related learning outcomes

Knowledge:
1. student can define the fundamental concepts in quantum mechanics and quantum computing within the frame of program contents - [K_W02]
2. student can roughly explain the principle of quantum state manipulation (basic quantum logic

operations), the idea of basic quantum algorithms, as well as describe basic architecture of quantum computers - [K_W02]

Skills:
1. student can apply the metod of linear algebra for description of quantum states, their manipulation and measurement - [K_U04]
2. student can use with understanding the indicated sources of knowledge (the list of basic literature references), as well as obtain knowledge from other sources (including sources in English language) - [K_U01, K_U02]
3. student can plan the procedure of quantum state tomography of an isolated qubit or a system of two qubits (in photonic polarization implementation), interpret the results of quantum state measurement, use the quantum random number generator - [K_U01, K_U04]
4. student can design, according to specification and with the use of functional modules, a simple system for preparation and coherent transformation of quantum states of single photon polarizations, can configure such a system and use it for quantum manipulation of photons' states - [K_U01, K_U04]
5. student can design and investigate exemplary systems for separation and observation of isolated single quantum objects (electromagnetic planar trap for single charged particles, single photon detector based on an avalanche photodiode) - [K_U01, K_U04]

Social competences:
1. student can get actively involved in solving of the problems, unaided develop and extend his/her competences - [K_K01]
2. student can cooperate within the team, fulfill the duties entrusted within the division of work in the team, show responsibility for his/her own work as well as for the effects of the team work - [K_K01]

## Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

W01,W02,U02: written exam
U01: written test
3.0: 50.1%-60.0%
3.5: 60.1%-70.0%
4.0: 70.1%-80.0%
4.5: 80.1%-90.0%
5.0: from 90.1%
U03,U04,U05: current evaluation of student's preparation for laboratory classes and written report of laboratory classes
3.0: student can perform the exercise according to the detailed instruction
4.0: student can configure the measurement system unaided according to the schematic diagram and perform the exercise according to the instruction
5.0: student can design and configure the measurement system unaided, perform the exercise according to the instruction and perform the quantitative analysis of the results
K01: evaluation of activity at tutorials
3.0: student shows moderate commitment
4.0: student shows commitment and self-dependence
5.0: student shows commitment and self-dependence, searches for new solutions
K02: evaluation of realization of a laboratory exercise

## Programme content

1. Elements of quantum mechanics (description n Hilbert space)
2. Basic concepts
3. Quantum software
4. Quantum hardware
5. Selected practical problems (photonic implementation of qubits

## Course topics

Program of the lecture:
1. Elements of quantum mechanics

- quantum states in Hilbert space
- orthonormal basis
- superposition of states
- basic properties of operators (including: eigenvalue problem)
- quantum measurement
2. Basic concepts
- qubits - quantum states, evolution of a quantum state, manipulation of quantum states
- quantum correlations, entanglement
- density matrix
- Bloch vector
- decoherence
3. Quantum software
- quantum gates
- basic quantum algorithms (Deutsch, Grover, Shor)
4. Quantum hardware
- fundamentals of implementation of a quantum computer (di Vincenzo criteria)
- selected implementations (including: nuclear spins, stored ions)

Program of the tutorials:
problems illustrating the program of the lecture, concerning selected topics
1. Fundamentals of quantum mechanics - quantum states operators, eigenvalue problem, quantum measurement
2. Manipulation of the qubit states
3. Entangled states
4. Density matrix - pure and mixed states
5. Bloch vector
6. Quantum gates
7. Quantum algorithms: Deutsch, Grover, Shor
8. Realization of the quantum gates on nuclear spins

Program of the laboratory classes:
1. Projection measurements of polarization states of light (sigma_1, sigma_2, sigma_3); quantum tomography of polarization states of light - determination of the relative phase of a qubit, transformation of polarization states of light with the use of optical retarders and birefringent crystals
2. Detectors of photons: determination of parameters (count rate) of a single photon detector based on an avalanche photodiode operated in Geiger mode with passive avalanche current quenching
3. Confinement and observation of ions in an electromagnetic Paul trap (optional)
4. Tests of a quantum random number generator
5. Demonstration of quantum interference in a Mach-Zehnder interferometer; quantum eraser

## Teaching methods

1. Lecture: presentation illustrated with animations and examples, solving of simple problems
2. Tutorials: solving of problems, discussion
3. Laboratory: realization of experiments, evaluation of results, discussion

## Bibliography

Basic:
1. J. Stolze, D. Suter, "Quantum Computing. A Short Course from Theory to Experiment", Wiley-VCH, 2004
2. M. Le Bellac, "Wstęp do informatyki kwantowej", Wydawnictwo Naukowe PWN, 2011
3. http://zon8.physd.amu.edu.pl/~tanas/QC.html, R. Tanaś, a course of popular talks in quantum computing
4. "Laboratorium Podstaw Inżynierii Kwantowej", unpublished materials

Additional:
1. M. Hirvensalo, "Algorytmy kwantowe", WSiP, 2004
2. C.C. Gerry, P.L. Knight, "Wstęp do optyki kwantowej", Wydawnictwo Naukowe PWN, 2007

## Breakdown of average student's workload

| | Hours | ECTS |
|---|---|---|
| Total workload | 128 | 5,00 |
| Classes requiring direct contact with the teacher | 68 | 3,00 |
| Student's own work (literature studies, preparation for laboratory classes/ tutorials, preparation for tests/exam, project preparation) | 60 | 3,00 |