SYLLABUS

1. Information regarding the programme

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| 1.1 Higher education institution | **Babeş-Bolyai University** |
| 1.2 Faculty | **of Physics** |
| 1.3 Department | **of Physics of the Hungarian line of study** |
| 1.4 Field of study | **Physics** |
| 1.5 Study cycle | **Master** |
| 1.6 Study programme / Qualification | **Computational Physics** |

2. Information regarding the discipline

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|---|---|---|---|---|---|---|---|
| 2.1 Name of the discipline | **Quantum Computing** | | | | | | |
| 2.2 Course coordinator | **Sándor Borbély** | | | | | | |
| 2.3 Seminar coordinator | **Sándor Borbély** | | | | | | |
| 2.4. Year of study | 1 | 2.5 Semester | 2 | 2.6. Type of evaluation | E | 2.7 Type of discipline | DA |

3. Total estimated time (hours/semester of didactic activities)

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|---|---|---|---|---|---|
| 3.1 Hours per week | 4 | Of which: 3.2 course | 2 | 3.3 seminar/laboratory | 2 |
| 3.4 Total hours in the curriculum | 56 | Of which: 3.5 course | 28 | 3.6 seminar/laboratory | 28 |
| Time allotment: | | | | | hours |
| Learning using manual, course support, bibliography, course notes | | | | | 23 |
| Additional documentation (in libraries, on electronic platforms, field documentation) | | | | | 29 |
| Preparation for seminars/labs, homework, papers, portfolios and essays | | | | | 30 |
| Tutorship | | | | | 9 |
| Evaluations | | | | | 3 |
| Other activities: .................. | | | | | |

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| 3.7 Total individual study hours | 94 |
| 3.8 Total hours per semester | 150 |
| 3.9 Number of ECTS credits | 6 |

4. Prerequisites (if necessary)

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| 4.1. curriculum | |
| 4.2. competencies | • quantum mechanics, programming in Python |

5. Conditions (if necessary)

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| 5.1. for the course | • |
| 5.2. for the seminar /lab activities | • |

6. Specific competencies acquired

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| **Specific competences** | • **Using in-depth knowledge of physics, mathematics, and programming in various multi- and inter-disciplinary fields.**<br>• **Applying quantum physics to understand of complex scientific phenomena.**<br>• **By exploiting the quantum nature of light understand, use and develop quantum communication (quantum key distribution) protocols.**<br>• **Measure and manipulate the polarization state of photons.**<br>• **Design and perform single photon experiments.**<br>• **Use of quantum circuit construction packages.**<br>• **Run quantum circuits through cloud solutions.**<br>• **Understand, use and develop new quantum circuits to resolve complex (hard) computational problems.**<br>• **Transform optimization problems to a form, which is solvable by adiabatic quantum computers**<br>• **Use of quantum annealers for the solution of optimization problems.** |
| **Transversal competences** | • **Accomplishment of professional tasks in an effective and responsible manner, in compliance with the field-specific legislation and code of ethics.**<br>• **Implementation of effective interdisciplinary teamwork methods at various hierarchical levels.**<br>• **Effective use of information sources, as well as communication and professional-assisted training resources in both mother tongue and English.** |

7. Objectives of the discipline (outcome of the acquired competencies)

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| 7.1 General objective of the discipline | • The students should acquire basic knowledge about quantum communication and quantum cryptography.<br>• The student should acquire basic knowledge regarding quantum circuit and adiabatic quantum computing.<br>• The students should acquire basis skills in using cloud computing infrastructure in order to access available quantum computers (quantum optimizers). |
| 7.2 Specific objective of the discipline | • The students should become familiar with the experimental techniques used during the manipulation and measurement of polarization states of light.<br>• The student should become familiar with the experimental techniques used during single-photon experiments.<br>• The student should become familiar quantum circuit logic and should be able to implement quantum computing algorithms.<br>• The students should become familiar with concept of adiabatic computing and of the quantum annealer.<br>• The students should form their skills for programming the applications of these methods. |

8. Content

| 8.1 Course | Teaching methods | Remarks |
|---|---|---|
| 1. Introduction. Quantum communication. Quantum Key Distribution. | Explication, problematization, multimedia projection, computer exemplification. | |
| 2. No Cloning Theorem. Quantum Teleportation, Bell inequality. | | |
| 3. Quantum vs. Classical bit. Multiple qubits. Measurements on qubits. Single qubit gates. Measurement gate. | | |
| 4. Multiple qubit gates. Circuit for the generation of Bell states. Quantum circuit for teleportation. | | |
| 5. Quantum parallelism. Deutsch and Deutsch-Jozsa algorithms | | |
| 6. Simulation of quantum systems on quantum circuits. Example: 1D Schrödinger equation. | | |
| 7. Quantum Fourier transform. Phase estimation | | |
| 8. Order Finding. | | |
| 9. Factoring as an order finding problem. Quantum search problem and Grover's algorithm. | | |
| 10. Quantum error correction. | | |
| 11. Adiabatic quantum computing. Quantum annealer. | | |
| 12. Technologies for the realization of quantum computers. | | |

Bibliography


1. M. A. Nielsen and I.L. Chuang, *Quantum Computing and Quantum Information*
2. E. Rieffel and W. Polak, *Quantum Computing: A Gentle Introduction*
3. M. A. Nielsen and I.L. Chuang, Quantum Computation: A Foundation for Quantum Information
4. V. Kasirajan, Fundamentals of Quantum Computing


| 8.2 Laboratory | Teaching methods | Remarks |
|---|---|---|
| 1. Linear polarization. Malus Law. Manipulation of the polarization direction. | Experimental work in the laser physics laboratory. Individual programing tasks is qiskit. | |
| 2. Polarimetry as a quantum state tomography. Elliptical and circular polarization | | |
| 3. Michelson Interferometer. The quantum eraser experiment. | | |
| 4. Characterization of the entangle single-photon pair source. | | |

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| 5. Simple quantum circuits (qubit swap, bell states, quantum teleportation) | |
| 6. Qiskit runtime | |
| 7. Quantum Fourier Transform part I | |
| 8. Quantum Fourier Transform part II | |
| 9-11. Individual projects | |
| 12. Error correcting circuits | |

9. Corroborating the content of the discipline with the expectations of the epistemic community, professional associations and representative employers within the field of the program

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10. Evaluation

| Type of activity | 10.1 Evaluation criteria | 10.2 Evaluation methods | 10.3 Share in the grade (%) |
|---|---|---|---|
| 10.4 Course | Knowlidge, understanding and capacity of application of quantum computing methods. | Oral exam | 50 |
| 10.5 Seminar/lab activities | Individual work | Written report for each Lab (25%)+ Written report for the large project (25%) | 50 |
| | | | |
| 10.6 Minimum performance standards | | | |
| 55% | | | |

Date ..26.06.2023………..

Signature of course coordinator ........... ...........................

Signature of seminar coordinator ..........................................

Date of approval ..........................................

Signature of the head of department ...........….........................