AGH University of Science and Technology

Code:	int.courses-299	Module name:	Quantum Mechanics & Quantum Computing

Academic year:	2018/2019	Semester:	Spring	ECTS credits:	4

Programme:	AGH UST International Courses

Course homepage:		Lecture language:	English

Responsible teacher:	prof. dr hab. inż. Koleżyński Andrzej (kolezyn@agh.edu.pl)
Academic teachers:	prof. dr hab. inż. Koleżyński Andrzej (kolezyn@agh.edu.pl)

Module summary

This course aims at an introduction to quantum computation, the cutting-edge field that tries to harness the amazing laws of quantum mechanics to process the information significantly more efficiently

Description of learning outcomes for module

MLO code	Student after module completion has the knowledge/ knows how to/is able to	Method of learning outcomes verification (form of completion)
Social competence		
M_K001	Student is prepared to effectively select appropriate algorithms of quantum computation to solve typical numerical problems.	
Skills		
M_U001	Student can analyze practical problem he/she is facing in quantum computing and select the appropriate algorithm to solve it.	Examination
Knowledge		
M_W001	Student has basic knowledge of fundamentals of quantum mechanics and its most important approximations.	Examination
M_W002	Student has basic knowledge of fundamentals of quantum algorithms and the basic ideas behind the experimental realization of quantum computers.	Examination

FLO matrix in relation to forms of classes

MLO code	Student after module completion has the knowledge/ knows how to/is able to	Form of classes										
		Lectures	Auditorium classes	Laboratory classes	Project classes	Conversation seminar	Seminar classes	Practical classes	Fieldwork classes	Workshops	Others	E-learning
Social competence												
M_K001	Student is prepared to effectively select appropriate algorithms of quantum computation to solve typical numerical problems.	-	+	-	-	-	-	-	-	-	-	-
Skills												
M_U001	Student can analyze practical problem he/she is facing in quantum computing and select the appropriate algorithm to solve it.	-	+	-	-	-	-	-	-	-	-	-
Knowledge												
M_W001	Student has basic knowledge of fundamentals of quantum mechanics and its most important approximations.	+	-	-	-	-	-	-	-	-	-	-
M_W002	Student has basic knowledge of fundamentals of quantum algorithms and the basic ideas behind the experimental realization of quantum computers.	+	-	-	-	-	-	-	-	-	-	-

Module content

Lectures

Topics covered in this course
1. Wave-particle duality, Heisenberg’s uncertainty principle.
2. Postulates of quantum mechanics and Schrodinger representation of QM: wavefunction, wavefunction space, linear Hermitian operators, eigenvalue problem, eigenfunctions, eigenvalues, the measurement problem, quantum contextuality (Kochen–Specker theorem), time evolution of wave functions, average values, expectation values, Ehrenfest’s theorem, Schrodinger equation,
3. Problems with analytical solutions: particle in a box, harmonic oscillator, hydrogen atom.
4. Multi-electron systems, the Pauli principle, electron spin, electronic configuration
5. Superposition of states and a concept of qubits (quantum bits), quantum entanglement, non-local correlations, the no-cloning theorem and quantum teleportation.
6. Classical Public Key and Quantum computational cryptography

7. The fundamentals of quantum algorithms.
8. The experimental realization of quantum computers.

Auditorium classes

Topics covered during these classes:
1. The qubit, Bloch sphere, decoherence.
2. Single-qubit gates, universal quantum gates.
3. Selected quantum algorithms: Deutsch–Jozsa, Shor’s, Grover’s, quantum phase estimation, quantum simulation, quantum optimization.
4. Quantum error correction.
4. Public key cryptography, elliptic-curve cryptography, RSA method, Public Key Infrastructure, digital signatures.
5. Quantum cryptography, quantum key distribution
6. Quantum teleportation.

Method of calculating the final grade

The final grade is calculated as a weighted average of partial grades: activity during classes (30%), attendance (10%) and exam results (60%).

Prerequisites and additional requirements

The course is intended for undergraduate students, including computer science majors who do not have any prior exposure to quantum mechanics, interested in gaining basic knowledge about foundations of modern quantum mechanics and its practical applications for quantum computation. The course does not assume any prior background in quantum mechanics and can be viewed as a very simple and conceptual introduction to that field.

Recommended literature and teaching resources

1. G. Benenti, G. Casati, G. Strini, Principles of Quantum Computation and Information. Volume I: Basic Concepts, World Scientific Publishing Co. Pte. Ltd. (2004).
2. M. A. Nielsen, I.L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press New York (2010)
3. J.A. Jones, D. Jaksch, Quantum Information, Computation and Communication, Cambridge University Press New York (2012)
4. E. Rieffel, W. Polak, Quantum Computing. A Gentle Introduction, The MIT Press (2011)
5. M. Le Bellac, A Short Introduction to Quantum Information and Quantum Computation, Cambridge University Press (2006)
6. D. Mermin, Quantum Computer Science: An Introduction, Cambridge University Press, (2007)

Scientific publications of module course instructors related to the topic of the module

1. A. Koleżyński, “FP-LAPW study of anhydrous cadmium and silver oxalates: electronic structure and electron density topology”, **Phys. B, 405** 3650–3657 (2010); DOI: 10.1016/j.physb.2010.05.059.
2. J. Leszczyński, A. Koleżyński, K.T. Wojciechowski, “Electronic and transport properties of polycrystalline Ba8Ga15Ge31 type I clathrate prepared by SPS method”, **J. Sol. State Chem.**, **193** 114-121 (2012); DOI: 10.1016/j.jssc.2012.03.067.
3. W. Szczypka, P. Jeleń, A. Koleżyński, “Theoretical studies of bonding properties and vibrational spectra of chosen ladder-like silsesquioxane clusters”, **J. Mol. Struct.**, **1075** 599–604 (2014), DOI: 10.1016/j.molstruc.2014.05.037.
4. A. Koleżyński, P. Nieroda, K. T. Wojciechowski, “Li doped Mg2Si p-type thermoelectric material: theoretical and experimental study”, **Comp. Mat. Sci.**, **100** 84–88 (2015), DOI: 10.1016/j.commatsci.2014.11.015.
5. A. Mikuła, M. Król, A. Koleżyński, “The influence of the long-range order on the vibrational spectra of structures based on sodalite cage”, **Spectrochim. Acta. A**, **144** 273–280 (2015), DOI: 10.1016/j.saa.2015.02.073.
6. P. Nieroda, A. Kolezynski, M. Oszajca, J. Milczarek, K. T. Wojciechowski, “Structural and Thermoelectric

Properties of Polycrystalline p-Type Mg2-xLixSi”, **J. Electronic Mat.**, **45** 3418-3426 (2016), DOI: 10.1007/s11664-016-4486-5.
7. A. Koleżyński, W. Szczypka, “First-Principles Study of the Electronic Structure and Bonding Properties of X8C46 and X8B6C40 (X: Li, Na, Mg, Ca) Carbon Clathrates”, **J. Electronic Mat.**, **45** 1336–1345 (2016), DOI: 10.1007/s11664-015-4028-6.
8. A. Koleżyński, W. Szczypka, “Towards band gap engineering in skutterudites: The role of X4 rings geometry in CoSb3-RhSb3 system”, **J. Alloys Compd.**, **691** 299-307 (2017), DOI: 10.1016/j.jallcom.2016.08.235
9. E. Drożdż, A. Koleżyński, “The structure, electrical properties and chemical stability of porous Nb-doped SrTiO3 – experimental and theoretical studies”, **RSC Advances**, **7** 28898-28908 (2017), DOI: 10.1039/C7RA04205A.
10. J. Leszczyński, W. Szczypka, Ch. Candolfi, A. Dauscher, B. Lenoir, A. Koleżyński, “HPHT synthesis of highly doped InxCo4Sb12 – experimental and theoretical study”, **J. Alloys Compd.**, **727** 1178-1188 (2017), DOI: 10.1016/j.jallcom.2017.08.194.
11. W. Szczypka, A. Koleżyński, “Theoretical studies of cation sublattice ordering in AgSbTe2 and AgSbSe2 – Electron density topology and bonding properties”, **J. Alloys Compd.**, **732** 293-299 (2018), DOI: 10.1016/j.jallcom.2017.10.199.
12. A. Mikuła, E. Drożdż, A. Koleżyński, “Electronic structure and structural properties of Cr-doped SrTiO3– Theoretical investigation”, **J. Alloys Compd.**, **749** 931-938 (2018), DOI: 10.1016/j.jallcom.2018.03.317.

Additional information

The course starts with a simple introduction to the fundamental principles and concepts of quantum mechanics, emphasizing the paradoxical nature of the subject, including a superposition of states (and a concept of qubits – quantum bits), entanglement, non-local correlations, the no-cloning theorem and quantum teleportation. The course covers the fundamentals of quantum algorithms and discusses the basic ideas behind the experimental realization of quantum computers.

Student workload (ECTS credits balance)

Student activity form	Student workload
Participation in lectures	15 h
Participation in practical classes	15 h
Examination or Final test	2 h
Realization of independently performed tasks	40 h
Contact hours	15 h
Preparation for classes	15 h
Summary student workload	102 h
Module ECTS credits	4 ECTS