Centre for High Energy Physics
Faculty of Science
University of the Punjab, Lahore
Course Outline

Program	BSCP	**Course Code**	ACS 404	**Credit Hours**	3 (2+1Lab)
Course Title	**Quantum Computing**				

Course Introduction

This course is designed to provide the concepts of new era of computing. By explaining the power of quantum computer drawbacks of existing classical computing are also emphasized. Basic difference between classical computing and quantum computing are also discussed through the classical and quantum information and their respective logical gates, architecture, and their limitations. Simulation of basic algorithms and circuits will be implemented using Open quantum computing framework (OpenQCF) in C# and Qiskit. This course will also provide the overview and drawbacks of some of the exiting but important simulators of quantum computing. By developing simulated applications of quantum computing based on available environment of high-performance computing (HPC) students will be able to understand the core concepts of classical and quantum computing. Students will be able to design software that efficiently solves different complex problems of quantum physics.

Learning Outcomes

On the completion of the course, the students will:

1. Understand the basic principle of quantum mechanics and their application to quantum computing.
2. Understand the quantum mechanics of open system and related results. 3. Learn the use of quantum computing software.

Course Content

Week 1	Overview of Quantum Computing, Power of Quantum Computers, Current Status of Quantum Computing
	Classical Information (Bits), Logical Gates, Adder Subtractor, Multiplexer, Register, Memory, 32-64 Bit Register, Limitations of Classical Architecture, Overview of Parallel and Distributed Techniques
Week 2	Postulate of quantum mechanics for isolated system, Qubit: Spin 1⁄2, photon polarization, Linear algebra, Dirac Notation
	Uncertainty, Complex numbers, Dual Vector, Spanning set, Basis, dimensions, inner product
Week 3	Operator, Hermitian operator, normal operator, unitary operator, Pauli operator, Density operator, Observable, Outer product, tensor product, Eigen value and eigen vectors.
	Orthonormality, Superposition, Entanglement (Einstein locality and hidden variables, Bell inequalities), Measurement (Orthogonal measurement, generalized measurement and POVM), Teleportation, No-Cloning Theorem
Week 4	Quantum Gates, Quantum Registers, Quantum Memory
	Difficulties to have Quantum Computers

Week 5	Density matrix, Bloch sphere	
	Gleason’s theorem, Evolution of density operator.	
Week 6	Schmidt decomposition, Convexity	
	Quantum erasure, The GHJW theorem	
Week 7	The Aspect experiments.	
	Nonmaximal entanglement	
Week 8	Uses of entanglement, Dense coding	
	EPR quantum key distribution	
Week 9	Quantum Algorithms and Circuits, OpenQCF and Qiskit libraries for the Simulation of Quantum Algorithms and Circuits	
	Quantum Adder and its Simulation	
Week 10	Quantum Subtractor and its Simulation.	
	Quantum Multiplexer and its simulation.	
Week 11	Shor’s Factorization Algorithm and its simulation.	
	Circuits of Quantum entanglement and Teleportation.	
Week 12	Search Algorithm in Quantum Computing and its simulation.	
	Artificial Intelligence, Artificial neural networks (ANN)	
Week 13	Simulation of ANN, Applications of ANN in Physics (Theory), Applications of ANN in Physics (Experiment)	
	Quantum Artificial Intelligence, Basic Introduction of QAI, Advancement from Classical AI to QAI, Problems being faced by QAI, Future of QAI	
Week 14	Algorithms of Quantum AI, Quantum neural network (QNN)	
	Quantum Genetic algorithms	
Week 15	Applications of quantum neural networks, Data Analysis of Physics experiments	
	Applications of quantum neural networks, Data Analysis of Physics experiments	
Week 16	Solution of differential equation using QNN.	
	Solution of integral equation using QNN.	

Textbooks and Reading Material

1. Quantum Computation and Quantum Information, by M.A. Nielson and I.I Chuang, *Cambridge University Press* (2010).
2. The Temple of Quantum Computing, by Riley T. Perry, Lulu.com (2004).
3. Quantum Computing Explained by David McMahon, Wiley-Interscience (2007).
4. Quantum Computing, by Vishal Sahni, CRC Press (2017).
5. *From Classical to Quantum Shannon Theory*, by Mark M. Wilde, arXiv: 1106:1445 (2019)
6. Quantum Information, from foundation to quantum technology applications (2 Vol. Set), by Dagmar Brub, GerdLeuchs, *Wiley-VCH* (2019)
7. Introduction to Quantum Information Science, by VlatkoVedral, *Oxford University Press* (2006)

Teaching Learning Strategies
The instructor is required to make use of FORTRAN/C/C++/Mathematica/Python/C# to teach the concepts through visualization/antimutation and symbolic/numerical calculations. The students are required to solve a large portion of related exercises/questions/problems of the main textbooks.
Assignments: Types and Number with Calendar
At least two assignments and two quizzes. A course project may also be assigned.
Assessment

Sr. No.	Elements	Weightage	Details
1.	Midterm Assessment	35%	Written Assessment at the mid-point of the semester.
2.	Formative Assessment	25%	Continuous assessment includes Classroom participation, assignments, presentations, viva voce, attitude and behavior, hands-on-activities, short tests, projects, practical, reflections, readings, quizzes etc.
3.	Final Assessment	40%	Written Examination at the end of the semester. At least fifty percent of the question paper would involve new problems related to the concepts learned in the course. It is mostly in the form of a test, but owing to the nature of the course the teacher may assess their students based on term paper, research proposal development, field work and report writing etc.