MS QUANTUM INFORMATION SCIENCES

Course Title: **Introduction to Quantum Computing-(QI-801)**

Credits Hrs: **3**

Prerequisites: Linear Algebra, Basic Quantum Mechanics

Course Description:

This course provides a rigorous foundation in quantum computation, uniting mathematical formalism with computational implementation. Students will explore how quantum systems encode, process, and transform information through phenomena such as superposition, entanglement, and measurement. The course introduces the quantum circuit model, universal gate sets, and the design and analysis of core quantum algorithms, including Grover's search and Shor's factoring. Emphasis is placed on understanding quantum error correction, current hardware architectures, and the software ecosystems enabling quantum programming. By the end of the course, students will be equipped with both the theoretical and practical skills necessary to engage with research and applications in quantum information science, communication, and cryptography.

Course Learning Outcomes (CLOs). By the end of this course, students will be able to:

- Explain the principles of qubits, superposition, entanglement, and quantum measurement.
- Apply linear algebra and tensor formalism to analyze single- and multi-qubit systems.
- Construct, simulate, and optimize quantum circuits using universal gate sets.
- Explain and implement foundational quantum algorithms such as Grover's and Shor's.
- Discuss quantum error correction, noise, and hardware limitations in real systems.
- Evaluate the computational complexity and potential advantages of quantum algorithms over classical ones.

Course Contents

Week	Contents
1	**Foundations of Quantum Computing:** Historical development; classical vs

	quantum information; overview of quantum technologies and applications.
2	**Quantum States and Qubits:** Dirac notation, Bloch sphere, measurement postulates, and probabilistic interpretation.
3	**Tensor Products and Multi-Qubit Systems:** Quantum entanglement, Bell states, measurement correlations, reduced density matrices.
4	**Single-Qubit Gates:** Pauli matrices, Hadamard, phase, and rotation gates; representation in matrix form.
5	**Multi-Qubit and Controlled Gates:** CNOT, Toffoli, controlled-U, and universality of gate sets.
6	**Quantum Circuits and Quantum Parallelism:** Circuit diagrams, reversibility, and computational models.
7	**Midterm Examination Week**
8	**Quantum Algorithms I:** Deutsch–Jozsa and Bernstein–Vazirani algorithms; problem encoding and oracle design.
9	**Quantum Algorithms II:** Grover's search algorithm, amplitude amplification, query complexity.
10	**Quantum Algorithms III:** Shor's factoring algorithm, quantum Fourier transform (QFT), and phase estimation.
11	**Quantum Error Correction and Decoherence:** Noise models, bit-flip and phase-flip codes, Shor code, surface codes, and fault tolerance.
12	**Quantum Hardware Architectures:** Superconducting qubits, trapped ions, photonics, spin qubits, and topological systems.
13	**Quantum Programming Frameworks:** Practical introduction to Qiskit, Cirq, and Q#; circuit simulation and execution on quantum backends.
14	**Applications and Future Directions:** Quantum cryptography, communication networks, optimization, and emerging research areas.

Textbooks & References:

- Nielsen, M. A. & Chuang, I. L. *"Quantum Computation and Quantum Information."* Cambridge University Press, 2010.

- Yanofsky, N. & Mannucci, M. *“Quantum Computing for Computer Scientists.”* Cambridge University Press, 2008.
- Qiskit Textbook. *“Learn Quantum Computation Using Qiskit.”* IBM Quantum, 2023.
- Griffiths, D. J. *“Introduction to Quantum Mechanics.”* Pearson, 2018 (for mathematical background).

Assessments:

- Assignments: 10%
- Quizzes: 10%
- Midterm Exam: 30%
- Final Exam: 50%