FUNDAMENTALS OF QUANTUM COMPUTING

COURSE CODE: 23PY3103 | CREDITS 3
L T P S | Sessional Marks: 40
3 0 0 0 | End Exam: 3 Hours
End Exam Marks: 60

Prerequisites:

- Classical Computing: Binary numbers, Logic gates, Boolean algebra
- Basics of Quantum Mechanics

Course Outcomes:

After completion of this course, the students will be able to:

CO-1: Understand the fundamental principles of quantum mechanics relevant to quantum computing.

CO-2: Represent quantum information using qubits and quantum gates.

CO-3: Analyze entanglement and its role in transmitting classical information non-locally.

CO-4: Analyze Bell's theorem and its implications on quantum predictions.

CO-5: Identify practical applications of quantum information theory, such as quantum cryptography

Mapping of Course Outcomes with POs and PSOs

COs/POs - PSOs	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	P010	PO11	PO12	PSO1	PSO2
CO-1	3	2	-	-	-	-						2	2	1
CO-2	3	3	2	-	2	-						2	2	2
CO-3	2	3	2	2	2	-						2	2	2
CO-4	2	3	-	2	-	-						2	2	1
CO-5	2	2	2	2	3	1						3	3	2

Correlation levels 1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

UNIT - I: Fundamentals of Quantum Mechanics 10 Lectures

Wave Function (ψ) and Schrodinger Equation: Physical significance, Wave particle Duality, One-dimensional potential well: Eigen functions and Eigen values

Why Quantum Computing: Classical vs. Quantum computing, Key applications – (Decoherence, Cryptography and Optimization)

Qubits vs. Classical Bits: Definition and representation, Comparison between bits and qubits

Mathematical Preliminaries: Bra-ket notation, Matrix representation of Quantum States, Inner and Outer products, Tensor product and their significance,

Learning Outcomes:

- Explain the key principles of quantum mechanics relevant to computing.
- Differentiate between classical and quantum computing.
- Understand how quantum states are represented mathematically.

UNIT - II: Single Qubit Quantum Systems **10 Lectures**

Qubit States and Representation: Vector Space and Hilbert Space, Complex vectors and qubits in $\mathbb{C}^2$, Bloch Sphere representation of a Qubit

Single-Qubit Measurement and Operations: Measurement outcomes and probabilities, Basic Quantum gates (**Pauli gates (X, Y, Z)** – Analogous to classical NOT gate, **Hadamard gate (H)** – Creates superposition states, **Phase shift gates (S, T)** – Introduces phase changes **Rotation gates (Rx, Ry, Rz)** – Rotates qubits in Bloch Sphere), Representation of gates using matrices

Learning Outcomes:

- Represent qubits using vector spaces and Bloch Sphere.
- Perform quantum operations using single-qubit gates.
- Understand the mathematical framework of quantum gate operations.

UNIT - III: Multiple Qubit Systems and Entanglement **10 Lectures**

Two-Qubit Systems: Representation and transformation of Two Qubit States, Tensor products and entanglement, The CNOT gate

Entangled States: Visualization and preparation of entangled states, Examples of entangled states in quantum computing

Learning Outcomes:

- Understand how multi-qubit systems interact.
- Analyze quantum entanglement and its role in quantum computing.
- Implement two-qubit gates in quantum circuits.

UNIT - IV: Measurement and Bell's Theorem **10 Lectures**

Quantum Measurement Formalism: Projection operators, Hermitian operators and their significance

Quantum Non-locality and Bell's Theorem: Einstein–Podolsky–Rosen (**EPR**) Paradox and, Bell's inequality and its Significance.

Learning Outcomes:

- Explain quantum measurement and its mathematical formalism.
- Analyze Bell's theorem and its impact on quantum mechanics.
- Evaluate experimental results verifying Bell's inequality.

UNIT - V: Quantum Circuits and Applications **10 Lectures**

Introduction to Quantum Circuits: Operations and representation, Classical vs. Quantum computations, Representation of quantum operations in circuit diagrams

Multi-Qubit Gate Operations: Controlled Gates (CNOT, CZ, Toffoli)– Entanglement and logic operations, Universal Gate Sets – How quantum gates can perform universal computation

Applications: Super-dense coding, Quantum teleportation, Quantum cryptography

Learning Outcomes:

- Implement quantum circuits using multi-qubit gate operations.
- Apply quantum principles to real-world problems.
- Understand practical applications like quantum cryptography and teleportation.

Textbooks:

1. M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press.
2. N. David Mermin, *Quantum Computer Science: An Introduction*, Cambridge University Press.
3. Phillip Kaye, Raymond Laflamme, and Michele Mosca, *An Introduction to Quantum Computing*, Oxford University Press.

Reference Books:

1. V. Sahni, *Quantum Computing*, Tata McGraw-Hill.
2. E. Rieffel and W. Polak, *Quantum Computing: A Gentle Introduction*, MIT Press.
3. John Preskill, *Lecture Notes on Quantum Computation* (Available Online).