Course Description

Title: Introduction to Quantum Computing **Course Code: 18B14PH541**

L-T Scheme: 3-0 Course **Credits: 3**

Objectives: The course Quantum Computing is specifically designed to offer a pedagogical exposure for the students pursuing undergraduate level studies in computer science and electronics. This newly emerging discipline provides many exciting opportunities for the practitioners of physics and engineering. In the first half of the course we intend to cover some fundamental concepts of quantum computation and quantum information theory. In the second half of the course, we will touch upon advanced topics e.g., quantum algorithms and quantum communication.

Prerequisites: Students taking up this course are expected to be familiar with elementary calculus and matrix analysis. The necessary background in quantum mechanics and mathematical physics will be introduced as we go on in the course.

Course Contents:

Unit I: Introduction & Overview: A brief historical review of basic ideas of classical computation and its scope and limitations. Basic definitions of quantum logic and quantum information. Basic ideas of classical information theory; measures of information (information content and entropy); Maxwell's demon, classical theory of computation; universal computer; Turing machine; computational complexity; uncomputable functions; shortcomings of classical information theory and necessity of quantum information theory. Stern-Gerlach experiment for illustration and existence of electron spin, basic idea of superposition of states. **[10]**

Unit II: Theoretical Framework of Quantum Computation: Dirac notation and Hilbert spaces, dual vectors, linear operators. The spectral theorem, functions of operators. Tensor products, Schmidt decomposition theorem. State of a quantum system, time evolution of a closed quantum system, measurement in quantum mechanics. Pure and mixed states, density operator, partial trace, general quantum operators. Bloch Sphere representation of single qubit states, qubit rotations, single qubit gates. **[12]**

Unit III: Quantum Model of Computation: The quantum circuit model, single and multiqubit operations, universal sets of quantum gates. Efficiency of approximating unitary transformations, implementing measurements with quantum gates. **[10]**

Unit IV: Quantum Algorithms: Probabilistic versus quantum algorithms. Phase kickback. The Deutsch and Deutsch-Jozsa algorithms. Quantum phase estimation and quantum Fourier transform, error analysis in arbitrary phase estimation. Finding orders, Shor's algorithm for order estimation. Quantum algorithms based on amplitude amplification, Grover's quantum search algorithm and related topics. **[8]**

Unit V: Quantum Entanglement & Teleportation: Mathematical and physical conceptions of quantum entanglement, entanglement distillation, entanglement of formation. Entanglement in pure and mixed states. No-Cloning theorem for quantum states. Quantum teleportation and quantum communication. **[5]**

Text Books & References:

1. Quantum computing explained, D.M. McMahon
2. Approaching Quantum Computing, D.C. Marinescu and G.M. Marinescu
3. Quantum Computation and Quantum Information, M.A. Nielsen and I.L. Chuang
4. An Introduction to Quantum Computing, P. Kaye, R. Laflamme and M. Mosca
5. Explorations in quantum computing, C.P. Williams and S.H. Clearwater
6. Introduction to quantum computers, G.P. Berman
7. The Physics of Information Technology, N. Gershenfeld
8. Quantum Computing, M. Hirvensalo
9. Quantum computing and communications: an engineering approach, S. Imre, F. Balazs
10. Quantum computing: a short course from theory to experiment, J. Stolze, D. Suter
11. The Principles of Quantum Mechanics, P.A.M. Dirac
12. Modern Quantum Mechanics, J.J. Sakurai
13. Problems and solutions in quantum computing and quantum information, W.H. Steeb, Y. Hardy
14. Mathematical Physics, S. Hassani, Springer Verlag

Course Outcomes:

Course Outcomes	**Description**
CO1	Provides basic ideas and limitations of classical computation. Introduces quantification of information in terms of Shannon's Entropy. Provides fundamental ideas of Quantum Physics and their applicability in computation and information processing.
CO2	Demonstrates theoretical framework of Quantum Computation, Linear Algebra, Dirac's notation, linear operators, tensor product, Hilbert spaces. Enables one to work with Gram- Schmidt orthogonalization process. Introduces ideas of quantum measurement, quantum states, their time-evolution and geometrical representation using Bloch-sphere. Provides examples of manipulation of single qubit states.
CO3	Establishes ideas of the Quantum Model of Computation, enabling one to work with simple quantum circuits and quantum logic gates; involving single and multi-qubit states.
CO4	Provides a comparison of probabilistic and quantum algorithms. Demonstrates quantum algorithms such as Deutsch, Deutsch-Jozsa algorithms, Shor's algorithm, Grover's search algorithm.
CO5	Establishes fundamental ideas of quantum entanglement, entanglement in pure and mixed states, No-Cloning theorem for quantum states. Quantum teleportation and Quantum communication.