

|           |                                      |          |   |   |   |   |        |                         |
|-----------|--------------------------------------|----------|---|---|---|---|--------|-------------------------|
| 25UECT414 | INTRODUCTION TO<br>QUANTUM COMPUTING | Category | L | T | P | R | Credit | Year of<br>Introduction |
|           |                                      | PEC      | 3 | 0 | 0 | 0 | 3      | 2025                    |

**Preamble:** This course introduces the fundamental concepts of quantum computing, including quantum bits, quantum mechanics, computational models, quantum circuits and algorithms, as well as quantum information theory topics such as noise, error correction, and entropy, providing students with a strong theoretical foundation in this rapidly advancing area of technology.

**Prerequisite:** Nil

**Course Outcomes:** After the completion of the course, the student will be able to:

| CO  | Course Outcomes                                                                                              | Knowledge Level  |
|-----|--------------------------------------------------------------------------------------------------------------|------------------|
| CO1 | Describe the need for quantum computing and explain the fundamental concepts quantum computation.            | K2<br>Understand |
| CO2 | Apply quantum mechanics principles and computational models to perform quantum information-processing tasks. | K3<br>Apply      |
| CO3 | Construct and apply quantum circuits using universal gates and standard quantum algorithms.                  | K3<br>Apply      |
| CO4 | Apply quantum information processes to ensure reliable quantum communication and computation.                | K3<br>Apply      |

**Mapping of course outcomes with program outcomes and program specific outcomes**

|     | PO1 | PO2  | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PSO1 | PSO2 |
|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|
| CO1 | 3   | 2    | -   | -   | -   | -   | -   | -   | -   | -    | 2    | 3    | 1    |
| CO2 | 3   | 3    | 2   | -   | -   | 2   | -   | -   | -   | -    | 3    | 3    | 2    |
| CO3 | 3   | 3    | 3   | 1   | -   | 3   | -   | -   | -   | -    | 3    | 3    | 2    |
| CO4 | 3   | 3    | 2   | 1   | -   | 2   | -   | -   | -   | -    | 3    | 3    | 3    |
| Avg | 3   | 2.75 | 2.3 | 1   | -   | 2.3 | -   | -   | -   | -    | 2.75 | 3    | 2    |

**Mapping of course outcomes with Knowledge and Attitude Profile (WK)**

|     | WK1 | WK2 | WK3 | WK4 | WK5 | WK 6 | WK7 | WK 8 | WK9 |
|-----|-----|-----|-----|-----|-----|------|-----|------|-----|
| CO1 | *   | *   | *   | *   |     |      |     | *    |     |
| CO2 | *   | *   | *   | *   | *   |      | *   | *    |     |
| CO3 | *   | *   | *   | *   | *   |      | *   | *    |     |
| CO4 | *   | *   | *   | *   | *   |      | *   | *    |     |

#### Wks Mapped with the course

| WK1 | WK2 | WK3 | WK4 | WK5 | WK6 | WK7 | WK8 | WK9 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| *   | *   | *   | *   | *   | *   | *   | *   |     |

#### Mark Distribution:

| Total Marks | CIE Marks | ESE Marks | ESE Duration |
|-------------|-----------|-----------|--------------|
| 100         | 40        | 60        | 2.5 hrs      |

#### Continuous Internal Evaluation Pattern:

|                            |            |
|----------------------------|------------|
| Attendance                 | : 5 marks  |
| Continuous Assessment Test | : 25 marks |
| Assignment                 | : 10 marks |

#### SYLLABUS

##### Module 1 (10 hrs)

Need for Quantum Computing and fundamental concepts, Global Perspectives – Quantum Bits – Quantum Computation – Quantum Algorithms – Experimental Quantum Information Processing – Quantum Information.

##### Module 2 (12 hrs)

Quantum Mechanics: Linear Algebra – Postulates of Quantum Mechanics – Application: Superdense Coding – Density Operator – The Schmidt Decomposition and Purifications – EPR and the Bell Inequality – Computational Models: Turing Machines – Circuits – Analysis of Computational Problems.

##### Module 3 (10 hrs)

Quantum Circuits: Quantum Algorithms – Universal Quantum Gates – Quantum Circuit Model of Computation – Simulation – Quantum Fourier Transform and Applications – Quantum Search Algorithms – Quantum Computers

##### Module 4 (10 hrs)

Quantum Noise and Quantum Operations: Classical Noise and Markov processes – Quantum Operations – Examples – Applications – Distance Measures for Quantum Information – Quantum Error Correction – Entropy

**Text Books:**

1. Nielsen, M. A., & Chuang, I. L. (2010). *Quantum computation and quantum information* (10th anniversary ed.). Cambridge University Press.
2. Easttom, C. (2021). *Quantum computing fundamentals* (1st ed.). Addison-Wesley Professional.

**Reference Books**

1. Aaronson, S. (2013). *Quantum computing since Democritus*. Cambridge University Press.
2. Nielsen, M. A., & Chuang, I. L. (2013). *Quantum computation and quantum information*. Cambridge University Press.
3. Mermin, N. D. (2007). *Quantum computer science: An introduction*. Cambridge University Press.

**END SEMESTER EXAMINATION – MODEL QUESTION PAPER**

|                       |                                          |
|-----------------------|------------------------------------------|
| <b>Course Code</b>    | <b>25UECT414</b>                         |
| <b>Course Name</b>    | <b>INTRODUCTION TO QUANTUM COMPUTING</b> |
| <b>Max. Marks: 60</b> | <b>Duration: 2.5 Hours</b>               |

| <b>Part A</b><br><i>(Answer all questions. Each question carries 3 marks)</i> |                                                                                                                                                                |              |           |           |
|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------|-----------|
| <b>Qn No.</b>                                                                 | <b>Question</b>                                                                                                                                                | <b>Marks</b> | <b>CO</b> | <b>BL</b> |
| 1                                                                             | Explain the need for quantum computing over classical computing. What are the fundamental limitations of classical computers that quantum computing addresses? | 3            | CO1       | L2        |
| 2                                                                             | What is a qubit? How does it differ from a classical bit? Explain superposition and entanglement with suitable examples.                                       | 3            | CO1       | L2        |
| 3                                                                             | State the postulates of quantum mechanics. How do these postulates form the foundation for quantum information processing?                                     | 3            | CO2       | L2        |
| 4                                                                             | Explain the EPR paradox and Bell's inequality. What is the significance of Bell's theorem in quantum information?                                              | 3            | CO2       | L3        |
| 5                                                                             | What is the quantum Fourier Transform (QFT)? How does it differ from the classical Discrete Fourier Transform (DFT)?                                           | 3            | CO3       | L2        |
| 6                                                                             | Describe Grover's quantum search algorithm. What is the quantum speedup achieved compared to classical search?                                                 | 3            | CO3       | L2        |
| 7                                                                             | Define quantum noise and Markov processes in the context of quantum systems. How does decoherence affect quantum computation?                                  | 3            | CO4       | L2        |

| 8                                                                                             | Explain quantum entropy (von Neumann entropy). How is it related to classical Shannon entropy? Give an expression and example.                                                                                       | 3     | CO4 | L2 |
|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-----|----|
| <b>Part B</b><br><i>(Answer any one full question from each Module. Each carries 9 marks)</i> |                                                                                                                                                                                                                      |       |     |    |
| Qn No.                                                                                        | Question                                                                                                                                                                                                             | Marks | CO  | BL |
| <b>Module I</b>                                                                               |                                                                                                                                                                                                                      |       |     |    |
| 9 a)                                                                                          | Describe the global perspectives and current state of quantum computing. Discuss the major milestones achieved in experimental quantum information processing with suitable examples.                                | 5     | CO1 | L2 |
| 9b)                                                                                           | Explain quantum algorithms with reference to Shor's algorithm and Deutsch-Jozsa algorithm. How do these demonstrate quantum supremacy over classical approaches?                                                     | 4     | CO1 | L2 |
| <b>OR</b>                                                                                     |                                                                                                                                                                                                                      |       |     |    |
| 10 a)                                                                                         | Explain quantum bits (qubits) in detail. Describe the Bloch sphere representation of a qubit and how single-qubit states are visualised geometrically.                                                               | 5     | CO1 | L2 |
| 10b)                                                                                          | Discuss the concept of Quantum Information as distinct from classical information. Explain the no-cloning theorem and its implications.                                                                              | 4     | CO1 | L2 |
| <b>Module II</b>                                                                              |                                                                                                                                                                                                                      |       |     |    |
| 11a)                                                                                          | Review the necessary linear algebra concepts for quantum mechanics: vector spaces, inner products, tensor products, Hermitian and unitary operators. Illustrate each with quantum examples.                          | 5     | CO2 | L3 |
| 11b)                                                                                          | Explain Superdense Coding with a circuit diagram. How does it allow transmission of two classical bits using one qubit?                                                                                              | 4     | CO2 | L3 |
| <b>OR</b>                                                                                     |                                                                                                                                                                                                                      |       |     |    |
| 12a)                                                                                          | Explain the density operator formalism. How is it used to describe mixed states? Define and interpret the purity of a state                                                                                          | 5     | CO2 | L3 |
| 12b)                                                                                          | Describe the Schmidt decomposition theorem and purification of quantum states. Explain the EPR argument and how Bell inequalities experimentally confirm quantum entanglement.                                       | 4     | CO2 | L3 |
| <b>Module III</b>                                                                             |                                                                                                                                                                                                                      |       |     |    |
| 13. a                                                                                         | Explain the quantum circuit model of computation. Describe the role of universal quantum gates (Hadamard, CNOT, Toffoli, Phase gate). Show how any unitary operation can be approximated using a universal gate set. | 5     | CO3 | L3 |
| 13. b                                                                                         | Describe the Quantum Fourier Transform algorithm step by step.                                                                                                                                                       | 4     | CO3 | L3 |

|                  |                                                                                                                                                                                                                           |   |     |    |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|-----|----|
|                  | Illustrate with a 3-qubit example and explain its application in phase estimation.                                                                                                                                        |   |     |    |
| <b>OR</b>        |                                                                                                                                                                                                                           |   |     |    |
| 14. a            | Explain Grover's quantum search algorithm in detail. Derive the number of iterations required for maximum success probability and analyse its quadratic speedup over classical search.                                    | 5 | CO3 | L3 |
| 14. b            | What are quantum simulators and quantum computers? Compare the circuit model of quantum computation with the Turing machine model. Discuss the role of simulation in validating quantum algorithms.                       | 4 | CO3 | L2 |
| <b>Module IV</b> |                                                                                                                                                                                                                           |   |     |    |
| 15. a            | Explain the quantum operations (Kraus operator-sum representation) formalism. Describe at least three examples of quantum noise channels: bit-flip, phase-flip, and depolarising channels with their Kraus operators.     | 6 | CO4 | L3 |
| 15. b            | Define distance measures for quantum information: trace distance and fidelity. State their properties and explain their significance in quantifying how close two quantum states are.                                     | 3 | CO4 | L2 |
| <b>OR</b>        |                                                                                                                                                                                                                           |   |     |    |
| 16. a            | Describe the theory of quantum error correction. Explain the three-qubit bit-flip code and the Shor code with encoding circuits. Why is quantum error correction fundamentally different from classical error correction? | 6 | CO4 | L3 |
| 16. b            | Discuss classical Markov processes and their quantum analogue. Explain how von Neumann entropy is used to quantify quantum information and describe its key properties (subadditivity, concavity).                        | 3 | CO4 | L2 |

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