NIRMA UNIVERSITY

Institute:	Institute of Technology
Name of Programme:	MTech CSE, MTech CSE (Cyber Security) and MTech (Data Science)
Course Code:	6CS465ME22
Course Title:	Quantum Computing
Course Type:	Department Elective-II
Year of Introduction:	2022-23

L	T	Practical Component				C
		LPW	PW	W	S	
2	0	2	-	-	-	3

Course Learning Outcomes (CLO):

At the end of the course, students will be able to –

1. explain the basics of quantum operation and gates (BL2)
2. analyse the classes of problems that are solvable by quantum computers (BL4)
3. interpret the models for quantum computing (BL5)
4. design quantum circuits and algorithms on related problems in Computer Science. (BL6)

Unit	Contents	Teaching Hours (Total 30)
Unit-I	**Physical Quantum Mechanics:** Schrodinger's time-dependent equation, Wave nature of particles, Hilber space, state vector, operators, Probabilities and measurements, postulates of quantum mechanics, Dirac formalism, Stern-Gerlach experiment, Bell inequalities and entanglement, Schmidt decomposition, super-dense coding, and teleportation	06
Unit-II	**Quantum Computing**: Limitations of conventional computing, Turing machines and halting problem, quantum computation, quantum bits, block sphere representation of a qubit, multiple qubits, conventional quantum mechanisms, states, density operators, quantum operations, channels, and no-cloning theorem	05
Unit-III	**Quantum Circuits and gates:** Quantum circuits, Density matrix, Simons algorithm, The wire and gate model, Universal set of gates, Toffoli gate, quantum circuits, Solovay-Kitaev theorem, and Deutsch-Jozsa algorithm	08
Unit-IV	**Quantum Information Theory**: Shannon entropy, noiseless coding theorem, von Neumann entropy and properties, Schumacher compression, noisy-coding theorem, Distance measures, Knill-Laflamme conditions, Hamming bounds, quantum error-correcting codes, and error correction models	06
Unit-V	**Quantum Cryptography:** Period-finding, factoring, Shor's algorithm, quantum search, Grover's search algorithm, quantum Fourier transform, Abelian quantum hidden subgroup problem, quantum key distribution, entropic uncertainty relations, Quantum-RSA, BB84, B-92, and Eckart protocol, basic realization model of a quantum computer.	05

Self-Study:
The self-study contents will be declared at the commencement of the semester. Around 10% of the questions will be asked from self-study content.

Suggested Readings/ References:

1. Michael A. Nielsen and Issac L. Chuang, Quantum Computation and Information, Cambridge University Press
2. Mikio Nakahara and Tetsuo Ohmi, Quantum Computing, CRC Press
3. N. David Mermin, Quantum Computer Science, Cambridge University Press
4. T. Hienosaari & M. Ziman, The mathematical language of quantum theory: from uncertainty to entanglement, Cambridge University Press
5. A.S. Holevo, Quantum systems, channels, information, De Gruyter Studies in Mathematical Physics
6. Mark M. Wilde, Quantum Information Theory, Cambridge University Press
7. D. A. Lidar & T. A. Brun, Quantum error correction, Cambridge University Press
8. Relevant research papers on these topics.

Suggested List of Experiments:

Sr. No.	**Name of Experiments/Exercises**	**Hours**
Qiskit based Practicals		
1	Introduction to IBM Qiskit and integration qiskit libraries in Jupyter notebook, and design of basic quantum circuit based on supplied information bits, an adder implementation	02
2	In Qiskit, create a state vector that will give a 1/3 probability of measuring $\|0\rangle\|0\rangle$, and then create a different state vector that will give the same measurement probabilities. Verify that the probability of measuring $\|1\rangle\|1\rangle$ for these two states is 2/3	02
3	Construct a compiled version of quantum circuit for Shor's algorithm.	04
4	Create quantum circuit functions that can compute the XOR, AND, NAND and OR gates using the NOT gate (expressed as x in Qiskit), the CNOT gate (expressed as cx in Qiskit) and the Toffoli gate (expressed as ccx in Qiskit)	04
5	Investigate the relationship between the number of qubits required for the desired accuracy of the phase estimation with high probability	04
6	Construct a circuit for quantum counting implementing the IPE (Iterative Phase Estimation) algorithm to find the number of solutions to a search problem	04
7	Create circuits for 3-qubit code that encodes a one qubit state into a three-qubit code state and utilize partiy check to detect and localise either bit-flip (X) or phase-flip (Z) errors on a single qubit in the codes	02
8	Solve the 3-SAT problem through the Grover's algorithm	04
9	Create a hybrid classical nueral network using Qiskit and Pytorch	02
10	Implement image encoding in quantum states, through the Flexible Representation of Quantum Images (FRQI) and the Novel Enhanced Quantum Representation (NEQR).	02