Minor Specialization in "Quantum Technologies"

		MINOR SPECIALIZATION				
S.No	**Semester**	**Course Name**	**L**	**T**	**P**	**Credits**
1	III	Survey and Foundations of Quantum Technologies	3	1	0	4
2	IV	Solid State Physics & Quantum Materials	3	1	0	4
3	V	Basics of Quantum Computation & Quantum Communication	3	1	0	4
4	VII	Programming for Quantum Technologies	2	0	2	3
5	VIII	Minor Project	0	0	6	3
		Total				**18**

Course Name	**:**	**Survey and Foundations of Quantum Technologies**
Course Code	**:**	**QTM 101**
Credits	**:**	**4**
L T P	**:**	**3 1 0**

Course Objectives :
Students should be able - • To understand the basics of quantum physics required for quantum computation • To learn the fundamental physical principles that enable the realization of qubits for quantum computation. • To describe its potential applications of quantum sensing in real-world scenarios. • To learn the basic quantum communications protocols in fibre-based and free-space.

Total No. of Lectures – 42

Lecture wise breakup		**No. of Lectures**
Unit 1	**Quantum Technologies**: four verticals, Motivation for Quantum Technologies, A qualitative overview of salient aspects of quantum physics, State vectors and Hilbert Space, Dirac Bra-Ket notation, Measurables and Hermitian Operators, Unitary Transformations, Schrodinger Equation and Time evolution of quantum states, Measurement Postulate, Schrodinger, Heisenberg and Interaction pictures, Eigen values, Expectation values and Matrix elements	**10**
Unit 2	**Quantum Computation:** Basics of qubits -- what is a qubit? How is it different from a classical bit? – Review of classical logic gates, Di Vincenzo criteria for realizing qubits, Basics of qubit gates and quantum circuits, Physical implementation of qubits (very qualitative description), Solid State Qubits: Semiconducting Qubits – quantum dots, spins, Superconducting Qubits – charge, flux and phase, Topological Qubits – proposals and advantages, Atoms and Ions: Trapped ions, Rydberg atoms, Neutral atoms, Photonic Qubits: Conventional linear optical setups, Integrated Photonics, NMR qubits: Conventional NMR qubits, NV centres	**12**
Unit 3	Density operator formalism of quantum mechanics – pure and mixed states, Superposition and Entanglement in quantum mechanics, RSA and Shor's algorithm, Quantum Advantage, Long term goals and strategies being followed, Error correction **Quantum Sensing** Basics of quantum sensing, Basics of Photon (single and entangled) generation and detection, Gravimetry, Atomic clock, Magnetometry, State of the art in Quantum Sensing	**10**
Unit 4	**Quantum Communications** Basics of digital communication, Quantifying classical information – Shannon entropy, Basic ideas of quantum communication, security, eavesdropping, Overview of quantum communication achievements, Terrestrial – fibre-based, Free space, Satellite-based	**10**

Course Outcomes: After completion of course, students would be able to:	
1	Apply physical principles of quantum physics to solve basic problems.
2	Visualize various hardware implementations of qubits for computation
3	Interpret basic ideas of quantum sensing and its applications
4	Implement quantum communications protocols in fibre-based and free-space

Text Book:

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication / Reprint
1	Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press	2023
2	Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press	2010

Reference Books:

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication / Reprint
1	Elements of Quantum Computation and Quantum Communication, A. Pathak, Boca Raton, CRC Press	2015
2	An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca, Oxford University Press	2006
3	Quantum computing explained, David McMahon, Wiley	2008

Equivalent MOOCs courses

Sr. No.	Course Links	Offered by
1		

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	1	1	-	-	-	-	-	-	-	1	3	1	2
CO2	3	2	1	1	-	-	-	-	-	-	-	-	2	3	2
CO3	1	1	1	-	-	-	-	-	-	-	-	-	1	1	1
CO4	2	2	1	-	-	-	-	-	-	-	-	-	1	2	2

1-Low, 2-Medium, 3-High

Course Name	**:**	**Solid State Physics & Quantum Materials**
Course Code	**:**	**QTM 102**
Credits	**:**	**4**
L T P	**:**	**3 1 0**

Course Objectives :
Students should be able to - • Analyse the magnetic, and superconducting properties of quantum materials. • Identify and explain the key principles of quantum mechanics in the context of materials science. • To understand about new 2D materials like graphene, TMDCs. • To understand about topology and topological phases of matter.

Total No. of Lectures – 42

Lecture wise breakup		**No. of Lectures**
Unit 1	Beyond the Free electron model: Kronig-Penney Model, Periodic potential – Bloch Theorem, Band theory, Tight binding model, Phonons in Solids, One dimensional monoatomic and diatomic chains, Normal modes and Phonons, Phonon spectrum, Long wavelength acoustic phonons and elastic constants, Vibrational Properties- normal modes, acoustic and optical phonons.	**10**
Unit 2	Magnetism: Dia-, Para-, and Ferromagnetism, Langevin's theory of paramagnetism, Weiss Molecular theory, Superconductivity: Phenomenological description – Zero resistance, Meissner effect, London Theory, BCS theory, Ginzburg-Landau Theory, Type-I and type-II superconductors, Flux quantization, Josephson effect, High Tc superconductivity	**12**
Unit 3	2D materials: Graphene and its properties – single and few layers Transition Metal Dichalcogenides – Electronic and Optical Properties	**8**
Unit 4	Topological Phases of matter: Basics of Topology, Geometric phases - Berry Phase, Aharonov Bohm effect, Topological phases of matter, Survey of material growth techniques: Molecular beam epitaxy, Chemical vapor deposition, MOVPE, Pulsed laser deposition, Crystal growth techniques	**12**

Course Outcomes: After completion of course, students would be able to:	
1	Solve the problems related to band theory of solids
2	Apply the basics of magnetism and superconductivity
3	Select the new 2D materials like graphene, TMDCs for particular applications
4	Analyze topology and topological phases of matter

Text Book:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication / Reprint**
1	Condensed Matter Physics, M P Marder, 2^{nd} Edition, John Wiley and Sons, 2010	2010
2	Introduction to Solid State Physics, Charles Kittel, Wiley India Edition (2019)	2019
Reference Books:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication / Reprint**
1	Introduction to Superconductivity, Michael Tinkham, standard ed., Medtech (2017)	2017
2	Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press	2023

Equivalent MOOCs courses

Sr. No.	**Course Links**	**Offered by**
1		

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	2	2	2	-	-	-	-	-	-	-	-	-	1	1	2
CO2	3	2	2	-	-	-	-	-	-	-	-	-	2	1	3
CO3	3	3	2	-	-	-	-	-	-	-	-	-	3	1	3
CO4	3	2	2	-	-	-	-	-	-	-	-	-	3	1	2

1-Low, 2-Medium, 3-High

Course Name	**:**	**Basics of Quantum Computation & Quantum Communication**
Course Code	**:**	**QTM 103**
Credits	**:**	**4**
L T P	**:**	**3 1 0**

Course Objectives :
Students should be able - • To understand the basic ideas of quantum gates • To learn the working of important quantum algorithms • To understand the fundamentals of polarization optics, photodetection, and digital communication theory. • To apply the principles of modulation, detection, and channel encoding to quantum systems.

Total No. of Lectures – 42

Lecture wise breakup		**No. of Lectures**
Unit 1	Qubits versus classical bits Spin-half systems and photon polarizations, Trapped atoms and ions, Artificial atoms using circuits, Semiconducting quantum dots, Single and Two qubit gates – Solovay - Kitaev Theorem Quantum correlations: Entanglement and Bell's theorems Review of Turing machines and classical computational complexity: Time and space complexity (P, NP, PSPACE) Reversible computation, Universal quantum logic gates and circuits	**12**
Unit 2	Quantum algorithms Deutsch algorithm, Deutsch Josza algorithm, Bernstein - Vazirani algorithm, Simon's algorithm Database search: Grover's algorithm Quantum Fourier Transform and prime factorization: Shor's Algorithm. Quantum complexity classes	**8**
Unit 3	Basics of Polarization optic: Quarter and half-wave plates, Polarizing beam splitters, Basics of linear and square-law detectors, Quadrature amplitude modulation, Heterodyne and Homodyne demodulation and linear detectors, Intensity measurements and square law detectors, Photomultipliers, Avalanche Photo diodes	**12**
Unit 4	Digital communication - Information entropy (basics) information entropy, Noiseless channel encoding, Noisy channel encoding, No cloning theorem, Quantum Memories, Quantum repeaters, Entanglement and Bell Theorems, Bell Measurements and Tests Quantum Teleportation protocol, Quantum Dense coding	**10**

Course Outcomes:
After completion of course, students would be able to:

1	Apply quantum gates to design quantum circuits.
2	Apply quantum algorithms for basic problems.
3	Interpret key concepts of optics in information theory.
4	Analyze core ideas and protocols in quantum communication.

Text Book:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication / Reprint**
1	Quantum computation and quantum information – Nielsen and Chuang Cambridge University Press, Cambridge	2010
2	Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press	2023
Reference Books:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication / Reprint**
1	A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)	2015
2	Quantum computing explained, David McMahon, Wiley (2008)	2008

Equivalent MOOCs courses

Sr. No.	**Course Links**	**Offered by**
1		

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	3	2	1	-	-	-	-	-	-	-	-	3	2	2
CO2	2	3	2	2	-	-	-	-	-	-	-	-	2	2	2
CO3	2	2	2	1	-	-	-	-	-	-	-	-	2	2	1
CO4	2	3	1	1	-	-	-	-	-	-	-	-	2	2	3

1-Low, 2-Medium, 3-High

Course Name	**:**	**Programming for Quantum Technologies**
Course Code	**:**	**QTM 104**
Credits	**:**	**3**
L T P	**:**	**2 0 2**

Course Objectives :
Students should be able - • To analyze fundamental algorithms • To apply computational techniques to solve real-world scientific problems. • To develop skills in scientific plotting and documentation of codes. • To enable develop problem-solving skills through hands-on coding in Python, Julia, or other relevant languages.

Total No. of Lectures – 28

Lecture wise breakup		**No. of Lectures**
Unit 1	**Basics of programming:** Data structures, classes, Object-oriented programming, Data storage and retrieval, Memory allocation, Scientific plotting, documentation of codes. Simple algorithms and benchmarking run time: Sorting, Searching, Arithmetic algorithms like GCD, Prime factorization	7
Unit 2	**Numerical Integration and differential equations:** Linear 2nd Order ODEs with constant coefficients, Linear 2nd order ODEs with variable coefficients, Boundary value problems, Poisson equation, Laplace equation, Wave equation, Diffusion Equation, Numerical techniques in linear algebra: Matrix inverse, Eigenvalue problem, Diagonalization of matrices, Singular value decomposition	7
Unit 3	**Numerical techniques in Probability and Statistics:** (Pseudo) Random number generation, Computing statistical moments for data samples, Least Squares fitting, Error Analysis, Hypothesis Testing, Monte Carlo sampling.	7
Unit 4	**Applications to Quantum Mechanics (using available modules in languages like Python):** Eigen energies of coupled two level systems, Eigen energies of two-level system coupled to oscillator (Jaynes-Cummings Model), Driven two-level system – Rabi Problem, Driven damped oscillator — coherent states. **Quantum Simulators** Running quantum protocols in a quantum simulator	7

Lab Practical
Qiskit (Quantum Information Software Kit) will be used to 1. Build a Quantum Random Number Generator 2. Implement Grover's Search Algorithm 3. Use Shor's Algorithm to Factor a Number 4. Find the Ground State Energy of a Lithium Hydride Molecule 5. Tackle Noise with Error Correction

6.	Explore Quantum Hardware with Qiskit Pulse
7.	Sort Images Using a Quantum Machine Learning Algorithm

Course Outcomes: After completion of course, students would be able to:	
1	Write programs to solve scientific problems
2	Analyze techniques for scientific computing
3	Apply QISKIT to solve basic quantum computing problems

Text Book:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication / Reprint**
1	Computational Physics, Nicholas Giordano, Hisao Nakanishi, 2nd edition, Pearson Addison Wesley	2005

Equivalent MOOCs courses

Sr. No.	**Course Links**	**Offered by**
1		

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	2	2	1	-	-	-	-	-	-	-	-	2	1	2
CO2	2	3	2	1	-	-	-	-	-	-	-	-	2	1	1
CO3	2	2	2	1	-	-	-	-	-	-	-	-	3	1	2

1-Low, 2-Medium, 3-High