Minor Basket for Quantum Technologies

	Course	L-T-P
1.	Survey of Quantum Technologies & Applications	3-0-0
2.	Foundations of Quantum Technologies	3-0-0
3.	Introduction to Quantum Materials	3-0-0
4.	Solid State Physics for Quantum Technologies	3-0-0

(a) Minor in Quantum Technologies Course Curriculum

Sl. No.	Course Name	Lab requirement	Credit	L-T-P
1.	Survey of Quantum Technologies and Applications	**No**	**3**	**3-0-0**
2.	Foundation of Quantum Technologies	**No**	**3**	**3-0-0**
3.	Introduction to Quantum Materials	**No**	**3**	**3-0-0**
4.	Solid State Physics for Quantum Technologies	**No**	**3**	**3-0-0**
		Total Credits	**12**	

Survey of Quantum Technologies and Applications 3:0

Course Outcomes:

Students of this course learn:

1. The general physical principles of realising qubits for computation
2. The various hardware implementations of qubits for computation
3. The basic ideas of quantum sensing
4. The applications of quantum sensing
5. The implementations of quantum communications protocols in fibre-based and free-space

Course Content and syllabus:

Quantum Technologies: Motivation for Quantum Technologies, A qualitative overview of salient aspects of quantum physics, Quantum postulates, Quantum States, Wavefunctions, Probabilistic interpretation, Physical observables, Hermitian operators, expectation values, Heisenberg uncertainty principle, Schrodinger equation, Time evolution, Harmonic oscillators, distinction from classical physics, Heuristic description of Superposition, EPR paradox and Bell's inequality, Tunnelling and entanglement, Simulating classical systems – Feynman's idea of a quantum simulator and the birth of the field

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 realising qubits, Basics of qubit gates and quantum circuits, Physical implementation of qubits (very qualitative description), **Overview of 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,

Overview of applications and recent achievements: Brief descriptions of quantum algorithms, networks, sensing, etc.

Quantum Communications: Basics of digital communication, Basic ideas of quantum communication, security, eavesdropping, Overview of quantum communication achievements, Terrestrial – fibre-based, Free space, Satellite-based.

Course References:

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)
3. Elements of Quantum Computation and Quantum Communication, A. Pathak, Boca Raton, CRC Press (2015)
4. An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca, Oxford University Press (2006)
5. Quantum computing explained, David McMahon, Wiley (2008).

Foundations of Quantum Technologies

Course outcome: Students of this course learn

1. The most relevant mathematical techniques
2. Basics of quantum gates, circuits, and algorithms
3. Basics of Statistical Physics
4. Basics of Information Science
5. Basics of computational complexity

Quantum Mechanics & Computing:

Density operators, Bloch sphere representation, Quantum Measurements, Composite systems, Entanglement, Bell's states, Schmidt decomposition.Quantum Gates, Quantum circuits, Quantum No Cloning Theorem, and Teleportation. Simple quantum algorithms: Deutsch Algorithm, Deutsch-Jozsa Algorithm, Grover Search problem.

Statistical Physics: Quick review of first and second laws of thermodynamics, Thermal Equilibrium and Gibbs principle, Applying Gibbs principle to Classical and Quantum harmonic oscillators, Bosons and Fermions and Quantum statistics – Fermi-Dirac and Bose-Einstein distributions

Information Science: Digital communication and information, Quantifying information in terms of Shannon entropy, Basic ideas of quantum information, Decoherence and noise, Introductory ideas of Kraus operators

Brief overview of Computational Complexity: Qualitative ideas of a Turing machine, Types of Turing machines, Time and Space complexity – P vs NP, PSPACE, Quantum complexity classes – Q, EQP, BQP, BPP, QMA, Post Quantum Cryptography (PQC)

Course References:

1. Introduction to Quantum Mechanics, Griffiths D. J., 3 rd Edition, Cambridge University Press (2024)
2. Introduction to Electrodynamics, Griffiths D. J., 4th edition, Cambridge University Press (2020)
3. Principles of Quantum Mechanics, Shankar, R., 2 nd edition, Springer (2014)
4. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
5. Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
6. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)
7. Information Theory, Robert B. Ash, Dover Publications (2003)
8. Introduction to the Theory of Computation, Michael Sipser, 3 rd edition, Cengage India Pvt. Ltd. (2014)
9. Statistical Mechanics, Pathria R. K., Paul D. Beale, 4th edition, Academic Press, (2021)

Introduction to Quantum Materials 3:0.

Students of this course learn
1. The basic idea of quantum materials
2. The basics of band theory of solids
3. The basics of magnetism
4. The basics of superconductivity
5. About new 2D materials like graphene, TMDCs
6. About topology and topological phases of matter

Course Content and syllabus:

Band theory basics: Metals, Semiconductors and Insulators, Band structure of solids, Survey of semiconducting devices for quantum technologies (electronic, quantum optical devices and principle of operation)

Correlated systems: Magnetism, Para, ferro magnetism basics, Magnetic measurements, hall effect, magnetoresistance, Faraday and Kerr effects

Superconductivity: BCS theory, Ginzburg Landau, Josephson Effect – AC and DC Josephson effects, Survey of superconducting devices for quantum technologies

2D materials: Graphene and its properties – single and few layers, Transition Metal Dichalcogenides – Electronic and Optical Properties

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, etc., Crystal growth techniques

Course References:

1. Condensed Matter Physics, M P Marder, 2nd Edition, John Wiley and Sons, 2010
2. Introduction to Superconductivity, Michael Tinkham, standard ed., Medtech (2017)

Solid State Physics for Quantum Technologies 3:0

Course Outcomes: Students of this course learn

1. Basics of solid-state physics
2. Various approximations for electronic states in matter
3. The theory of phonons in solids
4. The theory of magnetism
5. The theory of superconductivity

Course Content and syllabus:

Structure of solids: Symmetry, Bravais lattices, Laue equations and Bragg's law, Brillouin Zones, Atomic scattering and structure factors.

Characterisation of crystal structures XRD etc., Bonding in solids, van der Waals and Repulsive interactions, Lennard Jones potential, Madelung constant

The Drude theory of metals: DC & AC electrical conductivity of a metal; Hall effect & magnetoresistance, Density of states, Fermi-Dirac distribution, Specific heat of degenerate electron gases, Free electron model

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.

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

Course References:

1. Introduction to Solid State Physics, Charles Kittel, Wiley India Edition (2019)
2. Condensed Matter Physics, M P Marder, 2nd Edition, John Wiley and Sons (2010)
3. Introduction to Superconductivity, Michael Tinkham, standard edition, Medtech (2017)