

# Indian Institute of Space Science & Technology (IIST)

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Thiruvananthapuram



## Curriculum and Syllabus for M. Tech. in Quantum Technology Operative from 2022

Department of Physics

## Why M.Tech. in Quantum Technology?

The 20th century was witness to phenomenal advances in Physics. Besides enriching our understanding of sub-atomic and sub-nuclear physics over decades, concurrent technological developments also directly contributed in a big way to global progress. Much of the growth in living standards over the last 50 years can be singularly attributed to semiconductor electronics-based technologies. Over the years, rapid growth in these technologies has progressively resulted in faster, smaller, less power-hungry, and affordable end products. As it stands, the size of the smallest transistor today is just a few nanometers. This continued reduction in scale has also brought us to an epoch wherein we are staring at a threshold beyond which quantum features will dominantly govern the character of the devices.

As anticipated as it is inevitable, this new paradigm brings possibilities unseen and considered impossible until now. A host of technologies in a wide variety of application areas indispensable to modern living - communication, computation, sensing, and metrology, to name a few - have been entirely reworked, keeping into account the quantum rules of engagement in play. Most of these technologies have seen immense commitments towards research from both academia and industry in the past two decades, with some having crossed the stage of technology demonstration or even prototypes. For example, photonic, superconducting and atom-based quantum technologies outperform their classical counterparts. With several government labs, R&D establishments, and technology industries strongly invested in these developments, the field of quantum technologies has seen rapid growth, prompting an equivalent requirement for specialized scientific and technical human resources.

In India, national scientific establishments such as ISRO and DRDO are actively developing some of these technologies, especially quantum communication and sensing, which will be critical soon. There is also a larger national initiative from the Government of India to engage the academia, industries, and strategic research establishments, under a broader umbrella in pursuit of an early adaptation of these technologies.

The MTech in Quantum Technologies at IIST will join this global effort in preparing young engineering and science graduates, both towards industry and research, meeting the specific goals targeted by ISRO and other national scientific establishments. The outlined course work at IIST will provide a strong foundation with the required basics and give a broad overview of cutting-edge Quantum Technologies. The first semester lays the essential foundations where the student will be trained in the basics of quantum mechanics, solid state physics, optics, and experimental techniques, while simultaneously being introduced to quantum computation. In the second semester, the student covers various aspects of quantum technologies, such as quantum optical communication, quantum metrology, and quantum devices, while simultaneously being exposed to the physics of information. The student, in parallel, gets to perform several fundamental experiments as well as write elementary quantum computational codes as part of the curriculum. Apart from this, the student can choose one elective from a range of courses directly related to quantum technology in the second semester. The second year of the course is dedicated to the final year project, where the student will carry out academic as well as research and development based activity in any of the relevant quantum technology-related areas. The work carried out will have the potential to be publishable, with implications for the development and application of quantum technology.

## M Tech in Quantum Technology

### Program Educational Objectives (PEO)

- To train students to handle various quantum technologies-based applications required for research and industry.
- To train students with the potential for developing quantum technologies in Space Science and Development: Quantum communication, quantum cryptography, quantum sensing, etc.
- To train the students to think out-of-box of the usual curriculum through research-level projects and laboratory training.
- To develop new quantum technologies with the help of students, R&D labs, and Industries.

### Program Outcomes (PO)

- We will have students with a balanced skill set in fundamental and technological aspects of quantum technologies.
- We will have skilled students trained in quantum technologies to take up challenges in communications, cryptography, sensing, computing, spectroscopy and new materials.
- Students can join cutting-edge research and advanced futuristic devices directly.
- The program will generate human resources for the quantum technology-based Space Technology research to be a value-addition to the Indian Space Research program and other national scientific establishments.

### Educational qualifications for the admission:

B.E./B.Tech. or equivalent degree in Electronics/ Electrical Engineering/ Electronics and Communication Engineering/ Engineering Physics/Computer Science and Engineering/ Physical Sciences OR M.Sc. in Physics/ Applied Physics/Photonics/ M.S. (Integrated) Physics or related areas.

*A valid GATE score in Electronics and Communication Engineering/Electrical Engineering/ Physics/ Computer Science and Engineering*

## SEMESTER-WISE CREDITS

Semester	I	II	III	IV
Credits	17	18	15	20

### SEMESTER I

Course Code	Course Name	Course Credit L-T-P-C
PH634	Fundamentals of Quantum Mechanics	3-0-0-3
PH635	Solid State Physics	3-0-0-3
PH637	Electromagnetism and Optics	3-0-0-3
PH638	Quantum Computation	3-0-0-3
PH639	Experimental Techniques	3-0-0-3
PH657	Quantum Technology Lab 1	0-0-3-1
PH658	Quantum Simulation Lab	0-0-3-1
<b>Total Credits</b>		<b>17</b>

### SEMESTER II

Course Code	Course Name	Course Credit L-T-P-C
PH643	Quantum Optics and Quantum Communication	3-0-0-3
PH644	Quantum Metrology and Quantum Sensing	3-0-0-3
PH645	Physics of Information	3-0-0-3
PH646	Quantum Materials and Devices	3-0-0-3
PHXXX	Elective	3-0-0-3
PH647	Quantum Technology Lab 2	0-0-3-1
PH648	Quantum Technology Lab 3	0-0-3-1
PH649	Seminar	0-0-0-1
<b>Total Credits</b>		<b>18</b>

### SEMESTER III

Course Code	Course Name	Course Credit
PH753	Project- Phase I	15
PH756	Comprehensive viva	2
<b>Total Credits</b>		<b>17</b>

### SEMESTER IV

Course Code	Course Name	Course Credit
PH758	Project- Phase II	18
<b>Total Credits</b>		<b>18</b>

### LIST OF ELECTIVES

Course Code	Course Name	Course Credit L-T-P-C
PH711	Atomic and Molecular Spectroscopy	3-0-0-3
PH712	Optical Thin Films Science and Technology	3-0-0-3
PH713	Optical and Electro-Optical Sensors	3-0-0-3
PH714	Optical Communication	3-0-0-3
PH715	Advanced Optoelectronics	3-0-0-3
PH716	Statistical and Quantum Optics	3-0-0-3
PH717	Non-Linear Optics	3-0-0-3
PH718	Quantum Many-Body Physics	3-0-0-3
PH719	Device Physics and Nanoelectronics	3-0-0-3
PH720	MEMS and MOEMS	3-0-0-3
PH721	Cold Atoms and Bose-Einstein Condensates	3-0-0-3
PH722	High Resolution NMR Spectroscopy in Solids	3-0-0-3
PH723	Solid State NMR Spectroscopy	3-0-0-3
PH724	Quantum Information Processing	3-0-0-3

## SEMESTER I

PH634

Fundamentals of Quantum Mechanics

3 Credits

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- Linear vector spaces - inner product space - Hilbert space - examples Vectors and Tensors: Scalars and vectors, Orthonormal basis sets, Gram-Schmidt orthonormalization, Expansion of an arbitrary vector. The Cauchy-Schwarz inequality, the triangle inequality. Isotropic tensors, Rotations in three dimensions, Proper and improper rotations, scalars and pseudoscalars, polar and axial vectors
  - Group Theory: Discrete groups, cosets, factor groups, examples, Lie algebra, generators of continuous groups, examples (SU(2), SO(3), SU(3)).
  - Stern - Gerlach Experiment - State vector and State space - Postulates of quantum mechanics - Time evolution - Schrodinger equation - Particle in a box, infinite well - Tunneling.
  - Simple Harmonic oscillator - Creation and annihilation operators - spectrum - eigenstates
  - Rotations in three dimensions, Eigen states and eigenvalues of  $L^2$  and  $L_z$ , raising and lowering operators, Addition of angular momenta, Clebsch-Gordon coefficients.
  - Time independent and time dependent perturbation theory - examples.

### Textbooks and References

- Modern Quantum Mechanics, J J Sakurai and J Napolitano, Addison Wesley Publishers
- G B Arfken and H J Weber, Mathematical Methods for Physicists

PH635

Solid State Physics

3 Credits

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- **Bonding in Condensed matter Physics:** Forces and energy: interatomic bonding, Primary bonds: Covalent bonds, Ionic bonds, Metallic bonds etc. Secondary bonds: Van der Waals bonds, Hydrogen bonds etc.
  - **Crystal structure:** Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; Common crystal structures; Reciprocal lattice and Brillouin zone; Bragg-Laue formulation of X-ray diffraction by a crystal.
  - **Lattice dynamics and Specific heat:** Classical theory of lattice vibration under harmonic approximation; Vibrations of linear monatomic and diatomic lattices,

acoustical and optical modes, long wavelength limits; Normal modes and phonons; Inelastic scattering of neutron by phonon; Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity.

- **Band theory of solids:** Free electron theory, Limitations of free electron theory; Periodic potential and Bloch's theorem; Nearly free electron model; origin of Bands and band gaps; Tight binding method; Effective mass of an electron in a band: concept of holes; Energy band in one dimension, different zone schemes; E-k diagram in three dimensions, band structures and energy gap; Classification of metal, semiconductor and insulator; Density of states, Fermi energy and topology of Fermi surfaces.
- **Semiconductors:** Intrinsic semiconductors, statistics of electrons and holes in semiconductors, low-temperature approximation to Maxwell-Boltzmann Statistics. Extrinsic semiconductors: generation of donor and acceptor levels. Majority and minority carriers. Fermi levels in extrinsic semiconductors. Statistics of recombination: recombination mechanisms, carrier lifetime and photoconductivity. Defects in semiconductors. Carrier dynamics: Drift and diffusion of carriers, Einstein's diffusion relation, Thepn junction: depletion (space-charge) region, depletion layer width, continuity equation.
- **Magnetic properties of solids:** Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: quantum theory of paramagnetism; Mean field theory: Ferromagnetism, Curie-Weiss law, ferromagnetic domains; Heisenberg model (introduction), antiferromagnetism and ferrimagnetism.
- **Superconductivity:** Overview of superconductivity - Experimental survey; Zero resistance state, Meissner effect, flux quantization, London equations, penetration depth, isotope effect, specific heat. Type I and Type II superconductors. Electron-electron interaction via lattice: Cooper pairs and BCS formalism, multiband, High T<sub>c</sub> superconductors (qualitative discussion).

## Textbooks and References

- Ali Omar, Elementary Solid State Physics, Pearson
- N. Ashcroft and D. Mermin, Solid State Physics, Cengage.
- Charles Kittel, Introduction to Solid State Physics, Wiley.
- H. Ibach and H. Luth, Solid State Physics: An Introduction to Theory and Experiment, Springer.
- Solid State Physics, S.O. Pillai, New Age International Publications.
- Physics of Semiconductor Devices, S.M. Sze, Wiley Publications.
- Introduction to Superconductivity, A. C. Rose-Innes and E. H. Rhoderick, Pergamon.

- Introduction to electrostatics and magnetostatics, Maxwell's Equations, Electrometric waves in dielectric media, reflection, refraction, transmission, absorption and scattering. Metal dielectric interface, Plasmonics.
- Ray optics, Postulates of ray optics, Simple optical components, Matrix optics, The Ray-transfer matrix.
- Paraxial wave approximation of Maxwell's Equations. Huygen's principle, Fresnel and Fraunhofer diffraction. Imaging systems. Interference and interferometers.
- Paraxial polarization, Stokes parameters, Jones matrices.
- Lasers: Working principle, population inversion, optical resonators, three and four-level lasers, Ruby and He-Ne lasers.
- Nonlinear Optics: second and third order non-linear interactions, phase-matching, second and third harmonic generation.
- Integrated Photonics: Optical wave guide, fiber beam splitter and combiner, integrated resonators and filters, optical switching and modulators.

**Textbooks and References**

1. Fundamental of Photonics, by Saleh and Teich
2. Fundamental of Optics: Jenkins and White
3. Principle of Optics, by Born and Wolf
4. Optics, by Hecht
5. Introduction to Optics, Pedrotti, Pedrotti, and Pedrotti
6. Polarized Light, by Goldstein
7. Nonlinear Optics, by Boyd

- Review of Quantum Mechanics and Motivation for Quantum Computation
- Qubit: The qubit state - matrix and Bloch sphere representation - computational basis – unitary evolution.
- Multi-qubit states - No-cloning theorem - Superdense coding - Pure states to Bell states – Bell inequalities.
- Protocols with multi-qubits: Swapping - Teleportation - gates: CNOT - Toffoli gate - NAND - FANOUT - Walsh Hadamard



- Measurement: Projective operators - General, Projective and POVM measure.
- Ensemble: Density operators - pure and mixed ensemble - time evolution - post measurement density operator.
- Composite systems: Partial trace - Reduced density operator - Schmidt decomposition - Purification- bipartite entanglement.
- Quantum computing: Classical computing using qubits - Quantum parallelism - Deutsch's algorithm -Deutsch Josza algorithm.
- Quantum circuits: Basic gates - ABC decomposition - Gray codes - Universal gates - Principle of deferred and implicit measurements - Quantum Fourier transform - applications: phase estimation, order finding - factoring, discrete logarithm and hidden subgroup problems - Role of prime factoring in classical cryptography - search algorithms.
- Quantum error correcting codes
- Physical realization of qubits.

#### Textbooks and Reference:

1. Quantum Computation and Quantum Information, M. A. Nielsen and I. L. Chuang, Cambridge University Press
2. Quantum Information and Computation, CIT Lecture Notes by J. Preskill
3. Quantum Theory: Concepts and Methods, Asher Peres, Kluwer Academic Publishers

### PH639

### Experimental Techniques

### Credits 3

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- **Data analysis:** Probability distributions and statistics, uncertainty (error) analysis and its propagation, least-square fitting etc.
  - **Noise:** Various types of noise, and their origin, identification and isolation in an experimental environment. Ground, shield, Eddy currents. Differential Transmission, Modulation and Lockin measurement techniques.
  - **Vacuum technology:** gas flow equations, flow regimes, types of pumps, gauges, and seals, choosing the right equipment. Designing a UHV system, vacuum chambers, etc. Vacuum level and quality diagnostics, RGAs and mass spectrometers. Leak detection.
  - **Cryogenics:** production, detection, low and ultra-low temperatures using liquid  $^4\text{He}$ ,  $^3\text{He}$  and dilution refrigerators. Helium cryostats, adiabatic and nuclear

demagnetisation. Material properties at ultra-low temperatures. (Superfluidity, quasi-particle excitations). Temperature sensors.

- **Optical and spectroscopic techniques:**
  - Gaussian laser beams and beam characterization.
  - Saturated absorption spectroscopy, Fourier Transform (FT) Spectroscopy, Raman spectroscopy, Resonance spectroscopy: NMR, ESR etc.
  - Measurement of density of states and Fermi surface of metals: De Haas–van Alphen effect, Hall effect, X-ray/Neutron/electron diffraction, ARPES.
- Spectroscopy in *real* ( $r$ -space) and *momentum* ( $k$ ) space, Spectroscopic Imaging STM, ARPES.
- Electronic measurements

**Textbooks and References:**

1. Experimental Techniques in Condensed Matter Physics at Low Temperatures: Richardson and Smith
2. Matter and Methods at Low Temperatures: Frank Pobell, Springer.

**PH657**

**Quantum Technology Lab 1**

**Credits 1**

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- 1) Michelsen's interferometer
- 2) Mach-Zehnder interferometer and complementarity test.
- 3) Gaussian laser beam characterization
- 4) Tunneling of microwaves in a wax prism.
- 5) Polarization spatial entanglement
- 6) Stokes parameter measurement (state estimation problem)
- 7) Scanning Tunneling microscopy (STM) imaging (principle, hardware and scanning with atomic resolution on graphite surfaces: identification of carbon atoms)
- 8) I-z spectra in STM: experimental validation of tunneling through an infinite potential wall, estimation of workfunction of graphite.
- 9) Engineering 3D CAD drawing (Solidworks), basics of workshop processes and techniques.
- 10) Virtual instrumentation: General purpose instrumentation and computer interface, virtual instrumentation techniques and programming using Labview.

- 1) Introductions to programming. Quantum simulators for quantum circuits and algorithms using Qiskit and QuTiP;
- 2) Introduction to DFT, familiarization of the ATK simulation tool. Electronic structure of benzene /graphene.
- 3) Electronic configuration and band-structure of simple 2-dimensional materials: DFT simulations
- 4) Vibrational spectroscopy of simple molecules by DFT simulations: identification of Infrared and Raman modes.

## SEMESTER II

PH643

Quantum Optics and Quantum Communication

Credits 3

- Quantization of the Electromagnetic field, quadrature operators for fields, vacuum fluctuations and vacuum noise, uncertainty relation, number states, quantum phase, coherent states, phase space pictures of coherent states, squeezed states, photon number distributions in different states.
- Two level atom, interaction of light with matter, Jaynes-Cummings model.
- Twin-photon generation with non-linear interactions, parametric generation of light, spontaneous parametric down-conversion, optical parametric amplifiers and optical parametric oscillator.
- Linear Optics with Quantized Fields: Beam splitter transformations, single and two photon interference, Michelson and Mach-Zehnder interferometer, and Hong-Ou-Mandel dip.
- Theory of photodetection, direct, balanced, and homodyne detection
- Theory of optical coherence: Spatial and temporal coherence, van Cittert-Zernike theorem, Intensity interferometers, Hanbury-Brown-Twiss experiment, Photon-bunching and anti-bunching, quantum optical coherence.
- Experimental tools for realization of Quantum Optical Communication: Einstein-Podolsky-Rosen (EPR) Paradox, Entangled States, EPR Pairs: Photons with correlated polarization, Measuring the polarization of a single photon, Photon pairs and joint polarization measurements, EPR pairs with correlated polarizations, Bell's inequality: CHSH Variant, Quantum random number generation, Quantum Cryptography, Experimental implementation of single and entangled photon based Quantum Key Distribution protocols: BB84 and Ekert protocol. Quantum teleportation and dense coding, Quantum communication through- free space, fibers and satellites, quality check and privacy.

### Textbooks and References:

1. Introductory Quantum Optics, by Gerry and Knight
2. Quantum Optics, by G S Agarwal
3. A Guide to Experiments in Quantum Optics, by Hans and Bacher
4. Quantum Computation and Quantum Information, by Nielsen and Chuang
5. Introduction to Quantum Optics: From the Semi-classical Approach to Quantized Light, by Aspect, Fabre, and Grynberg.
6. Optical quantum information processing,, by Kok and Lovett

- Introduction to estimation theory, Bayesian methods, conditional probabilities, estimation errors, bounds on estimation errors, the Cramer-Rao inequality. Introduction to classical signals.
- Quantum states, density matrix, measurement, POVM. Probabilities in quantum mechanics, Naimark's theorem. Introduction to quantum estimation theory. Discussion on qubits, and other examples. The Quantum-Cramer-Rao inequality and bound. Estimation of a single parameter, time-energy uncertainty relation. Generalization to multi-parameter estimation.
- Quantum sensors and quantum sensing, Examples of Quantum sensors: Optical sensors based on light squeezing and photonic quantum correlations, standard quantum limit (SQL) and sensitivity beyond SQL.
- Quantum mechanical treatment of the Mach-Zehnder interferometer, the quantum advantage in interferometry: Phase estimation in interferometers, States with enhanced phase sensitivity, NOON state, etc, atom interferometers.
- Cold atoms, Cooling of atoms, techniques, laser cooling, magneto optical traps, BEC, spectroscopy in condensates, frequency standards, quantum gyroscopes, atom interferometers, Neutral atoms as magnetic sensors, Trapped ions and Rydberg atoms as electric field sensors, atomic clocks, nitrogen-vacancy centers, superconducting sensors.

#### Textbooks and References:

1. Quantum detection and estimation theory, C. W. Helstrom, Academic press.
2. Probabilistic and statistical aspects of quantum theory, A. S. Holevo, North-Holland.
3. A guide to experiments in quantum optics, H. A. Bachor and T. C. Ralph, Wiley
4. Atom interferometry: Proceedings, Tino, G M [Ed.] Italian Physical Society Villa Monastero 15-20 July 2013 International School of Physics "Enrico Fermi" Course 188: Proceedings.
5. The Quantum World of Ultra-Cold Atoms and Light Book II: The Physics of Quantum-Optical Devices, C Gardiner and P. Zoller, World Scientific.
6. Research papers

- Basic laws of thermodynamics. Equation of state. Potential formulation of thermodynamics. Connection between statistics and thermodynamics. Boltzmann equation-entropy.

- Microcanonical, canonical, and Grand canonical ensembles. Gibbs state. Classical and quantum harmonic oscillator, magnetization problem examples.
- Bose and Fermi-Dirac, and Boltzmann statistics, examples.
- Shannon entropy, properties, entropy as information, classical data compression.
- Density matrix formulation in quantum mechanics. Mixed states. Qubit and quantum harmonic oscillator examples. Gibbs state. von-Neumann entropy, properties. Quantum data compression.
- Bipartite pure states. Reduced density matrix. von-Neumann entropy as measure of bipartite entanglement.

### Textbooks and References:

1. Thermodynamics, Kinetic theory, and statistical thermodynamics, Sears and Salinger, Third edition, Narosa publishing, 1998
2. Statistical Mechanics, R.K. Pathria, Elsevier Publishing.
3. Fundamentals of statistical and thermal physics, F. Reif, Levant Books, 2010
4. Quantum Computation and Quantum Information, Nielsen and Chuang, Cambridge University Press.
5. Preskill Notes.
6. Quantum concepts and methods, Asher Peres, Kluwer Publishers.

**PH646**

**Quantum Materials and Devices**

**Credits 3**

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- Quantum electronics and Quantum logic
    - Quantum Dots: size quantization effects, Exciton confinements, increase in the bandgap, density of states of quantum dots, quantum 2D electron gas materials.
    - Quantum Conductance: ballistic transport, resistance quantization, derivation of Landauer formula, break-junction experiments. Tunnel junctions: tunnelling through single Quantum dots – Coulomb blockade phenomenon. Gated tunnel devices - Single electron transistors (SET), Coulomb diamonds, applications of SETs. Quantum dot Inverter operations. Quantum memory, Quantum dot based qubits
    - Quantum Optoelectronic devices: Quantum well lasers, Quantum dot lasers, Tunnel injection quantum dot lasers.
  - Single photon sources and detectors: Deterministic single-photon sources: Single atoms, ions and molecules, color centers of diamond, Quantum dots; Probabilistic

single-photon sources: spontaneous parametric downconversion in bulk crystals, four-wave mixing in optical fibers and atoms. Single photon detectors: Non-photon-number-resolving detectors single-photon detector: photomultiplier tubes, single-photon avalanche photodiodes, superconducting nanowire single-photon detectors. Single photon counting modules, time to amplitude converter.

- Quantum Devices at ultra-low temperature:
  - Transport spectroscopy and spintronics materials
  - Superconducting electronics: N-I-N, S-I-N, S-I-S tunnelling, Josephson effect, SQUID, single photon detection, topological insulators.
  - Candidates for quantum computer: optical, ion trap, atoms, superconductors.
  - Superconducting Quantum Computers
    - Qubit dynamics and coupling: two-state Quantum System, qubits and qubit control, entanglement.
    - Josephson Junction and Superconducting Quantum Interference Device (SQUID), Flux tuneable Josephson energy.
    - Quantized Electronic Devices: Canonical Quantization, Josephson Junction quantization, Josephson Junction Qubit.
    - Qubit state measurement and entanglement, coupling through Jaynes-Cummings Hamiltonian.
    - Superconducting Qubit, XMON Qubit Hamiltonian and eigenstates.
    - Quantum Supremacy • Google Sycamore QCPU: XMON State control, readout, entanglement, performance, QCPU operations, Qubit programmable QCPU.
    - Superconducting Quantum Computers: Google, IBM, Intel, Microsoft's topological quantum computer

#### Textbooks and References:

1. Experimental Techniques in Condensed Matter Physics at Low Temperatures: Richardson and Smith
2. Matter and Methods at Low Temperatures: Frank Pobell, Springer.
3. Single Photon Generation and Detection: Migdall, Polyakov, Fan and Bienfang.

**PH647**

**Quantum Technology Lab 2**

**Credits 1**

1) Scanning tunneling spectroscopy: Measurements of local density of states (LDOS) of various materials: estimation of bandgap and position of the Fermi levels

2) Fowler-Nordheim tunneling through an insulating material: estimation of band-offsets of metals with insulators.

3) Vacuum technology: how to achieve ultra-high vacuum

4) Cryogenics: towards absolute zero

5) Sensors and analogue instrumentation.

6) Superconducting levitation, physical properties of BCS and High T<sub>c</sub> superconductors

7) FPGA based electronics and post-processing protocols for QKD

8) Designing active filters

<b>PH648</b>	<b>Quantum Technology Lab 3</b>	<b>Credits 1</b>
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- 1) Demonstration of photon-statistics of different light sources
  - 2) Test of Bell's inequality
  - 3) Demo of BB84 using cryptography Kit
  - 4) Quantum random number generation
  - 5) Shot noise measurement of photons
  - 6) Saturated absorption spectroscopy
  - 7) Measurement of the numerical aperture of fibre; attenuation and dispersion in optical fibres
  - 8) WDM Mux, Demux and add drop multiplexing
  - 9) Fibre amplifier

<b>PHXXX</b>	<b>ELECTIVE I</b>	<b>Credits 3</b>
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<b>PH649</b>	<b>Seminar</b>	<b>Credits 1</b>
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**SEMESTER III**

<b>PH753</b>	<b>Project- Phase I</b>	<b>Credits 15</b>
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<b>PH756</b>	<b>Comprehensive Viva</b>	<b>Credits 2</b>
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**SEMESTER IV**

<b>PH758</b>	<b>Project- Phase II</b>	<b>Credits 18</b>
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## LIST OF ELECTIVE COURSES

**PH711**

**Atomic and Molecular Spectroscopy**

**Credits 1**

Atomic structure and spectroscopy: One and multi electron atoms, energy level notation schemes, interaction of electromagnetic radiation with atoms, Einstein's coefficients, line shape and broadening. Visible, UV and x-ray spectroscopy of atoms. Instrumentation and applications. Astronomical significance.

Molecular spectroscopy: Molecular structure, Group theory for molecular physics, Huckel model, HartreeFock, density functional calculation of di-atomic and poly-atomic molecules. Energy level structure and notation, electronics, vibrational and rotational structure. Visible, IR and microwave spectroscopy. Raman spectroscopy and its applications.

Resonance spectroscopy: Electron spin resonance, nuclear magnetic resonance, Magnetic Resonance Imaging. Mossbauer spectroscopy.

Mass spectroscopy: Mass spectrometer basics, instrumentation, ion traps as mass spectrometers, Paul and Penning traps, multipole traps. Fourier transform infrared spectroscopy.

### Text Books/References

1. Fundamentals of Molecular Spectroscopy By Banwell (4th edition, TMH).
2. Atomic and molecular spectroscopy: basic aspects and practical applications By Sune Svanberg (4<sup>th</sup> edition, Springer)
3. Modern spectroscopy By John Michael Hollas (4th edition, Wiley)
4. Quadrupole ion trap mass spectrometry By Raymond E. March, John F. J. Todd (2nd edition Wiley interscience)
5. Mass spectrometry: principles and applications By Edmond de Hoffmann, Vincent Stroobant (3<sup>rd</sup> edition, Wiley)
6. Mass spectrometry: instrumentation, interpretation, and applications By Rolf Ekman (Wiley interscience)
7. Charged particle traps Volume 1 By Fouad G. Major, Viorica N. Gheorghe, Gunter Werth (Springer)
8. Physics of atoms and molecules By B. H. Bransden, Charles Jean Joachain (2nd edition Prentice Hall)

Propagation of electro-magnetic in stratified dielectric medium, Fresnel equations Optical properties of materials, metals, semiconductors and dielectrics, optical glass materials in the visible and near infrared region, IR optical materials, Multilayer thin film optics, Antireflection coatings, Band pass optical filters, edge filters, dichroics, Design – Optimization techniques for thin film multilayer, Merit function as applied to thin film coatings. Brief review of different optimization techniques as applied to optical coatings. Case studies for design approaches for different categories of optical coatings. Exposure to thin film software packages.

Concept of linearly variable and circularly variable filters, Tunable optical filters. Reflective coatings, enhanced reflectors.

Thin film technology: Vacuum Science: Viscous, Lamellar and molecular fluid region, Medium, High and Ultra-high vacuum techniques. Mechanical and High vacuum pumps, ultra-high vacuum pumps. High vacuum measurement techniques, principle, calibration and electronics read out Deposition and production of optical thin films: Thin film deposition techniques thermal/electron beam evaporation, RF/DC sputtering, Ion beam sputtering, pulsed laser beam deposition. In-situ thickness monitoring: Optical and quartz micro-balance techniques monitoring techniques.

Architecture of modern day coating plants. Characterization of optical thin films: Principles of characterization of optical reflectance, transmittance, absorbance and angle resolved scattering. Principles of spectrophotometers and ellipsometers. FTIR spectrometers Characterization of non-optical properties of thin films: Mechanical adhesion, abrasion and hardness. Surface characterization techniques for thin films: Surface morphology, X-ray structure, Chemical composition. SEM, TEM and AFM instruments for thin film characterization.

Space qualification: Different environments encountered by Optical components in ground during storage, instrument assembly and testing, launching and in deep space. Adverse environmental conditions in deep space. Radiation environment in space. Space Qualification of Optical coatings and materials. Effect of space environment on optical materials and thin films.

### Textbooks and References

1. Thin film optical filters, Angus Macleod
2. Principles of optics, Born and Wolf
3. SPIE milestone series on -Design of optical coatings
4. Optical Thin films – User hand book – James D Rancourt SPIE Press – 1996 – ISBN 0819422851
5. Practical Design and Production of Optical Thin Films – Second Edition – Ronald Ron Wiley – CRC Press – 2002 ISBN 0824708490
6. Handbook of Thin Film Technology- Leon – Imaissel & Reihard Glang – Mc Graw – Hill Book Company-1970 – ISBN 0070397422

Sensor Overview: Photometry and Radiometry, Radiation Sources and characteristics. Detectors-Imaging and non imaging [Thermal detectors, Photon detectors, Detector arrays : CCDs, CID, FLIR etc.] and their characteristics.

Sensor optics, Sensor instrumentation, Signal processing techniques Space craft sensors: Optical Attitude Sensors: Fiber Optic gyros [with integrated optics], Ring Laser Gyros, Star sensors – Spacecraft attitude determination and control. Line of Sight Sensors – IR Earth sensor, Sun Sensors, Star Sensor & Trackers.

Sensors/System for Space craft precision Pointing and navigation. Imaging sensors: Remote sensing sensors for Earth observation, Cartography Hyper spectral Sensors.

Modeling, design, analysis, calibration and Performance evaluation of the above. System Integration and Testing. Optical, Integrated and Fiber optic sensors: Acceleration, Displacement and Velocity sensors [anemometer], Position – linear and Angle encoders, temperature, strain etc. Fiber optics based smart sensors for Space applications : MOEM Sensors, Large optical Systems for space born camera applications.: Design, Fabrication and Testing.

#### Text Books/References

1. Fundamentals of Space Systems by Vincent L. Pisacane, Oxford University Press, 2005
2. Spacecraft dynamics and Control: A practical Engineering approach- Marcel J. Sidi, Contributor Michael J. Rycroft, Wei Shyy, Cambridge University Press, 2000
3. Spacecraft Attitude determination and Control by Computer Sciences, Corporation Attitude Systems operation, James Richrad Wertz, Springer, 1978
4. Scientific Charge Coupled devices, James R. Janesick, SPIE Press
5. Laser Gyros and Fiber optic Gyros: Proceedings London Royal Aeronautical Society 1987
6. Fiber optic sensor-based smart materials and structures- By Claus, Richard O, Knowles, G J Bristol, Institute of Physics Publishing, 1992
7. Fiber optic gyroscope- By Lefevre, Herve, Boston, Arcteh House, 1993
8. Laser Inertial Rotation Sensors-proceedings- By Ezekiel, Shaoul, Knausenberger, G E Washington, Proceedings of SPIE. v157, 1978
9. Handbook of fiber optics : Theory and applications, Yeh, Chai, Academic Press, Inc., 1990.

Introduction to information theory- Shannon noiseless coding theorem and Shannon noisy coding theorem. Introduction to optical communication: Overview of General communication, advantage of optical communication, review of optical fibre and its propagation characteristics, signal attenuation in fibre, dispersion, classification and effect of dispersion in information transfer, review of fibre connectors, couplers, optical filter, isolator, circulator and attenuator.

Aspects of design of optical communication: optical fibre systems, modulation schemes, Digital and analog fibre communication system, system design consideration, emitter and detector design, fibre choice, connectors, various amplifiers and its characteristics.

Optical transmitter: Basic concepts, characteristics of semiconductor injection LASER, LED, transmitter design. Optical Receiver: Basic concepts, P-n and Pin photo detectors, Avalanche photo detectors, MSM photo detector, receiver design, receiver noise, receiver sensitivity, optical amplifier and its applications.

Coherent communication: Basic concept, detection principles, practical considerations, modulation and demodulation schemes, heterodyne and homodyne detection, single and multicarrier systems, DPSK field demonstrated system, multicarrier and network. Introduction to Advanced optical communication:

Wavelength division multiplexing (WDM): multiplexing techniques, topologies and architectures, wavelength shifting and reverse, switching WDM demultiplexer, optical add/drop multiplexers. Dense wavelength division multiplexing (DWDM): system considerations, multiplexers and demultiplexers. Fiber amplifier for DWDM, SONET/SDH transmission, modulation formats, NRZ and RZ signalling, DPSK system modeling.

### Text Books/References

1. Communication system - B.P Lathi
2. Optical fiber communications: Principles and practice- John M. Senior-Prentice Hall of India
3. Optical communication systems-John Grower- Prentice Hall of India
4. Optical fiber communications- Gerd Keiser-McGraw Hill, 3 ed.
5. Non-linear optics – G.P Agarwal- Academic Press
6. WDM optical networks: concepts, design and algorithms- C.Sivarammurthy and Mohan Gurusamy-Prentice Hall of India, 2002
7. Understanding SONET/SDT and ATM communication network for next millenium- Stamatis VKartalopoulos- Prentice Hall of India, 2000
8. Elements of Information theory, T M Cover and J A Thomas, Wiley, 2006

Review of Semiconductor device Physics, Semiconductor Opto electronics- Solid State Materials, Emitters, Detectors and Amplifiers, Semiconductor Emitters- LEDs, Diodes, SLDs, CCDs, Semiconductor lasers- basic Structure, theory and device characteristics, DFB, DBR, Quantum well lasers, Laser diode arrays, VCSEL etc. Semiconductor photo detectors: Materials - Si, Hg Cd Te, InGa As, Al Ga As, GaN etc for different wavelengths.

Detectors: Photoconductors, photo diodes, PIN, APD, Photo transistors, solar cells, CCDs, IR and UV detectors.

Band gap Engineering, Quantum well structures, size effects, Hetero and nano structures. Fabrication techniques [MBE, CVD, Lithography, Thin films technology] and Device characterization. Integrated Optics- Optical wave guide theory, wave guide structures. Fiber optic interconnects- Fiber lasers and amplifiers, fiber sensors.

Optoelectronic Integrated Circuits [OEIC]- Directional couplers, Dividers, Multiplexers, Phase and Amplitude Modulators, Polarization and polarization controllers, etc. Photonics Signal processing, Nonlinear optics- Frequency Converters, Phase conjugation, optical Correlation etc.

Photonic devices and applications for aerospace: Intensity, phase and polarization based Fiber optic sensors for measurement of temperature, pressure, stress etc for space craft health monitoring, Hydrogen leakage sensing in cryo engines. Fiber Optic Gyroscope for navigation application. Optical Intra Satellite links using ELED's, VCSELs. Fiber Bragg gratings for health monitoring and smart materials: applications in aerospace.

### Text Books/References

1. Physics of Opto-electronic Devices- Shun Lien Chuang-Wiley, John & Sons-2009
2. Physics of Semiconductor devices-S.M.Sze & Kwok K Ng, Third edition, Wiley-2007 [parts I, II and IV]
3. Infrared Photon detectors-Antoni Rogalski [Ed]-SPIE Optical Engineering Press-1995
4. CCD arrays, Cameras & Displays-Gerald C Hoist 1998 [2nd Ed], JCD Publishing-SPIE Optical.
5. Fundamentals of Photonics, by Bahaa E. A. Saleh and Malvin Carl Teich, Wiley Series in Pure and Applied Optics
6. Photonic Devices By Jia-Ming Liu Cambridge University Press, 2005
7. Photonic Devices and Systems –by Robert G. Hunsperger, Taylor & Francis, 1994

Introduction to probability theory, properties of probabilities, random variables and probability distribution, generating functions, examples of probability distributions, Gaussian probability distribution, central limit theorem, multivariate Gaussian distribution. Random processes, statistical ensembles, stationarity and ergodicity, properties of autocorrelation function, spectral properties of stationary random processes, orthogonal representation of a random process, Wiener Khinchine theorem, Karhunen–Loeve expansion.

Second order coherence theory of scalar wave fields, temporal coherence, spatial coherence, the laws of interference, the mutual coherence function and the complex degree of coherence, cross spectral density, partial coherence and spectral degree of coherence, Wigner function, propagation of cross-spectral density and mutual coherence in free space, the van Cittert–Zernike theorem and its application in stellar interferometry.

Elementary theory of polarization of stochastic electromagnetic beams. Polarized, unpolarized, and partially polarized light. Partially polarized light and the degree of polarization. Stokes parameters and the Poincaré sphere. Unified theory of polarization and coherence. Spectral degree of coherence and stochastic electromagnetic beams, generalized Stokes parameters.

Position and momentum kets, displacement operator. Wave functions in position and momentum space, the uncertainty principle. Simple harmonic oscillator, annihilation and creation operators, Fock basis, time evolution. Coherent, squeezed, and thermal states of a single-mode. Quantization of the electromagnetic field.

Representation of a state, Fock basis expansion, coherent state expansion, diagonal representation, Wigner phase space density, and the Q function, s-ordered quasi-probability. Normal, symmetric, and anti-normal ordering of operators. Classical and non-classical states of radiation with examples. Field correlation functions, properties of correlation functions, correlation functions and optical coherence.

Photon correlation measurements, photon counting measurements, Intensity – intensity correlation  $g_2(\tau)$ . The quantum mechanical beam-splitter, the quantum mechanical amplifier. Two-mode squeezed vacuum.

### Text Books/References

1. Statistical Optics, J. W. Goodman, Wiley–Interscience, 2000.
2. Optical Coherence and Quantum Optics, L. Mandel and E. Wolf, Cambridge University Press, 1995
3. Introduction to theory of coherence and polarization of light, E. Wolf, Cambridge University Press, 2007.
4. Modern Quantum Mechanics, J. J. Sakurai, Pearson Education, 2009.

5. Optical Coherence and Quantum Optics, L. Mandel and E. Wolf, Cambridge University Press, 1995.
6. Quantum Optics, D. F. Walls and G. J. Milburn, Springer, 2007.
7. The quantum theory of light, R. Loudon, Oxford university press, 2000.

## PH717

## Non-Linear Optics

Credits 3

Nonlinear optical susceptibility, wave equation description of nonlinear optical interactions - Sum frequency generation, Difference frequency generation, Second Harmonic generation, Phase matching condition,

Optical parametric Oscillators, Quantum mechanical theory of nonlinear optical susceptibility- Schrodinger equation calculation, density matrix calculation. Spontaneous light scattering and acousto optics, Stimulated Brillouin Scattering, Stimulated Rayleigh Scattering, Stimulated Raman Scattering, Second harmonic generation, parametric processes, 3rd order nonlinear optics, Kerr type nonlinearities, 4-wave mixing, selffocusing collapse, optical breakdown, two beam coupling, electrooptics and photorefractive effects, optically induced damage and multiphoton absorption, Ultrafast and intense field nonlinear optics and optical solitons.

### Text Books/References

1. Nonlinear optics, second Edition, Robert W Boyd, Academic Press (2003)
2. Photonics-Optical Electronics in Modern communications, A Yariv and P Yeh, Sixth edition, Oxford University Press (2007)
3. The Principles of nonlinear Optics, Y R Shen, Wiley-Interscience, 1991
4. Handbook of Nonlinear Optics, R L Sutherland, Marcel Dekker, 1996

## PH718

## Quantum Many-Body Physics

Credits 3

Second quantization: Fock space representation, creation and annihilation operators for bosons and fermions, representation of many-body operators.

Green's functions at zero temperature: Interaction representation, Wick's theorem, Feynman diagrams.

Finite temperatures: Matsubara functions, retarded and advanced Green's functions. Linear response, Kubo formula.

Interacting fermions: Fermi liquid theory, Hubbard model, Heisenberg model.

Electron-Phonon interaction, BCS theory of superconductivity.

### Text Books/References

1. A. Altland and B. Simmons, Condensed Matter Field Theory.
2. G. D. Mahan, Many-Particle Physics.
3. J. W. Negele and H. Orland, Quantum Many-Particle Systems

Introduction: Moore's law and technology development. International Technology Roadmap for Semiconductors (ITRS); Technology and material challenges limiting Moore's law.

Contacts: Fabrication of Junction, Metal-semiconductor contacts, Schottky barrier. Contact resistance: 2-probe and 4-probe measurements; Kelvin and van der Pau structures; pn junctions: carrier transport.

Equilibrium conditions, Steady state conditions, Transients and AC conditions.

MOS devices: Oxide charges and band-bending, Capacitance – Voltage (C-V) behavior of pMOS and nMOS devices, dissipation factor, band-diagram and degeneracy at accumulation and inversion, depletion width, Mott-Schottky plot and carrier concentration. Frequency dispersion of capacitance, correction of high-frequency capacitance, interface states, parallel conductance measurements, Equivalent oxide thickness (EOT); Leakage current mechanisms through MOS devices – space charges and Child's law, Schottky emission, direct tunneling, band diagram under external field: Fowler-Nordheim tunneling, Poole-Frenkel charge injection.

MOSFET devices: Process technology of fabricating a MOSFET, degenerate states of inversion and formation of the channel, Operation of a MOSFET: Output characteristics: conduction through the channel at low fields; linear regime and Ohm's law: surface mobility and bulk mobility of charges in a semiconductor.

Factors influencing the mobility and mobility saturation; pinch-off and drain-current saturation; Threshold voltage of a MOSFET, Sub-threshold conduction in a MOSFET, transfer characteristics, transconductance and subthreshold swing, cutoff frequency. The Non-ideal MOSFET behavior: effects of Schottky contacts, influence of the oxide charges.

MOSFET scaling: scaling roadmap, Short-channel effects: Short-channel effect in transfer and output characteristics.

Introduction to Nanoelectronics: Single molecule field effect transistors, Nanowire FET's, Single electron transistors, Single electron tunneling (SET) devices: Coulomb blockade phenomenon. Nano-scale flash memory devices – Yano memory devices, Resonant tunneling devices (RTD).

Optoelectronics devices: Photodiodes, Light emitting diodes, semiconductor lasers.

#### Text Books/References

1. S.M. Sze, Physics of Semiconductor Devices, Wiley Publications.
2. S. Dutta, Electronic Transport in Mesoscopic Systems, Cambridge University Press.
3. D. K. Schroder, Semiconductor material and Device Characterization, Wiley Interscience.



4. Nicollian and Brews, Metal-Oxide-Semiconductor Physics and Technology, Wiley Interscience.

## **PH720**

## **MEMS an MOEMS**

**Credits 3**

Introduction: Fourier Optics, Holography, Optical thin films and periodical structures Bragg gratings, photonic crystals, Gaussian beam propagation, ultra fast lasers, Fundamentals of Nonlinear Optics, Quantum optics.

MEMS: Introduction & applications, Substrates: Quartz, Ceramics, and Polymers.

Smart materials and their properties. Thin films in the context of smart materials, nano, & microtechnologies.

Lithography: Fundamentals. Materials such as photoresist used in lithography. Techniques such as using optical, electron beam, focused ion, x-ray beams. Etching and micro machining. Wet and dry etching, deep reactive ion etching. Packaging and bonding, micro-assembly. Reliability studies in packaging.

MEMS devices for applications such as in aerospace, biomedical and process industries.

MOEMS: MOEM overview, MOEM scanners, MOEM technology and applications to telecom, CMOS compatible MOEMS, optics specific issues for MOEMS, micro-optics, automation and sensing, shape memory actuators, piezoelectric actuators, magnetic actuators, MOEMS related sensors, micro-optic components, testing and applications.

### **Text Books/References**

1. Nodum Maluf, "An introduction to micromechanical systems engineering"
2. Marc Madou, "Fundamentals of micro fabrication" CRC press (1997).
3. Ristic (Ed) "Sensor Technology & Devices", Artech House Publications (1994).
4. MOEMS, SPIE Press, USA

## **PH721**

## **Cold Atoms and Bose-Einstein Condensates**

**Credits 3**

Atomic gases, Collisions and trapping, Interaction with the radiation field and optical traps, Light forces on atoms, Doppler and sub-Doppler cooling, Magneto-Optical Trap, evaporate cooling, Optical Lattices, Ion traps, experiments on cold atoms.

The Ideal Bose gas, Weakly-interacting Bose gas, Ground state energy and equation of state, Particles and elementary excitations. Nonuniform Bose gases at zero temperature, Gross-Pitaevskii equation, Thomas-Fermi limit, solitons, quantization and elementary excitations.

The ideal Bose gas in the harmonic trap, condensate fraction and critical temperature, density and momentum distribution, Ground state of a trapped condensate, Dynamics of a trapped condensate, Bose-Einstein condensate in optical lattices.

#### **Text Books/References**

1. L. Pitaevskii and S. Stringari, Bose-Einstein Condensation, Oxford (2003).
2. C.J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases, Cambridge (2008).
3. Christopher J. Foot, Atomic Physics, Oxford (2005).

### **PH722 High Resolution NMR Spectroscopy in Solids**

**Credits 3**

Nuclear spin interactions in solids: Basic nuclear spin interactions in solids, spin interactions in high magnetic fields, transformation properties of spin interactions in real space, powder spectrum line shapes, specimen rotation, rapid anisotropic molecular rotation, line shapes in the presence of molecular reorientation.

Multiple-pulse NMR experiments: Idealized multiple-pulse sequences, the four-pulse sequence (WHH4), coherent averaging theory, application of coherent averaging theory to multiple-pulse sequences, arbitrary rotations in multiple-pulse experiments, resolution of multiple-pulse experiments, magic angle rotating frame line narrowing experiments.

Double resonance experiments: Basic principles of double resonance experiments, cross-polarization of dilute spins, cross-polarization dynamics, spin decoupling dynamics.

Magnetic shielding tensor: Ramsey's formula, approximate calculations of the shielding tensor, proton shielding tensors, <sup>13</sup>C shielding tensors.

Spin-Lattice relaxation in line narrowing experiments: Spin-lattice relaxation in multiple-pulse experiments, application of multiple-pulse experiments to the investigation of spin-lattice relaxation, spin-lattice relaxation in dilute spin systems.

#### **Text Books/References**

1. M. Mehring, High Resolution NMR Spectroscopy in Solids, Springer-Verlag, 1976.

### **PH723 Solid State NMR Spectroscopy**

**Credits 3**

Theory of solid state NMR and its experiments: The basics of solid state NMR, the vector model of pulsed NMR, the quantum mechanical picture: Hamiltonians and the Schrodinger equation, the density matrix representation and coherences nuclear spin interactions, calculating NMR power patterns, general features of NMR experiments.

Essential techniques for spin- $1/2$  nuclei: Introduction, magic-angle spinning (MAS), high-power decoupling, multiple pulse decoupling sequences, average Hamiltonian theory and the toggling frame, cross-polarization, solid or quadrupole echo pulse sequence.

Dipolar coupling, its measurement and uses: Introduction, techniques for measuring homonuclear dipolar couplings, recoupling pulse sequences, double-quantum filtered experiments, rotational resonance, techniques for measuring heteronuclear dipolar couplings, spin-echo double resonance, rotational-echo double resonance, techniques for dipolar-coupled quadrupolar (spin- $1/2$ ) pairs, transfer of population in double resonance, rotational echo, adiabatic passage, double resonance, techniques for measuring dipolar couplings between quadrupolar nuclei, correlation experiments, homonuclear correlation experiments for spin- $1/2$  systems, homonuclear correlation experiments for quadrupolar spin systems, heteronuclear correlation experiments for spin- $1/2$ , spin-counting experiments, the formation of multiple-quantum coherences, implementation of spin-counting experiments.

Quadrupole coupling, its measurement and uses: The quadrupole Hamiltonian, the effect of RF pulses, high-resolution NMR experiments for half-integer quadrupolar nuclei, magic-angle spinning, double rotation, dynamic-angle spinning, multiple-quantum magic-angle spinning, other techniques for half-integer quadrupolar nuclei, quadrupole nutation.

Shielding and chemical shift: The relationship between the shielding tensor and electronic structure, measuring chemical shift anisotropies, magic-angle spinning with recoupling pulse sequences, variable angle spinning experiments, magic-angle turning, two-dimensional separation of spinning sideband patterns.

### Text Books/References

1. M. J. Duer, Solid State NMR Spectroscopy: Principles and Applications, Blackwell Science Ltd.

**PH724**

**Quantum Information Processing**

**Credits 3**

Introduction to Shannon entropy - classical information-classical information from measurements - von Neumann entropy - properties-subadditivity and concavity- quantum data compression - classical information in quantum mechanics- Holevo bound. Quantum Information.

Entanglement as a physical resource, teleportation, dense coding, as examples. Mixed state entanglement. Detection of bipartite entanglement, various methods. Bipartite entanglement measures. Multipartite entanglement.

Quantum noise and quantum operations - Operator-sum representation -qubit channels, decoherence. Distance measures - trace distance - fidelity, etc.

Quantum state tomography, unbiased measurements, mixed state reconstruction.

Quantum error-correction: Shor code - Quantum error correction -Stabilizer codes -fault tolerant quantum computation, decoherence free subspace.

Quantum state discrimination, error probability analysis, the quantum-Chernoff bound. Introduction to quantum illumination.

### **Textbooks and References:**

1. Quantum Computation and Quantum Information, M. A. Nielsen and I. L. Chuang, Cambridge University Press
2. Quantum Information and Computation, CIT Lecture Notes by J. Preskill
3. Quantum Theory: Concepts and Methods, Asher Peres, Kluwer Academic Publishers
4. Journal papers as necessary.