# Minor offered by the Department of Physics

| Quantum Technology | |
|---|---|
| **S. No.** | **Course Name** |
| 1-4 | Any four Courses from the **Quantum Science & Technology** Program Elective Basket |
| 5 | Mini Project |

## List of Program Electives

| S. No. | Program Elective Basket |
|---|---|
| | **Quantum Science & Technology** |
| 1. | Quantum Communication |
| 2. | Quantum Technology Lab |
| 3. | Quantum Sensing and Metrology |
| 4. | Quantum Materials and Devices |
| 5. | Quantum Optics |
| 6. | Foundation of Quantum Computation |
| 7. | Quantum Computing for Physical Systems |

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHTX XX | Quantum Communication | **3** | **2** | **1** | **0** | **0** |

**PREREQUISITE – Basic Quantum Mechanics and Optics courses**

**COURSE OBJECTIVE(s)**

The course aims to provide a foundational understanding of polarization optics, advanced photodetection, and classical information theory. Students will master key quantum communication protocols and analyze hardware implementations across fiber, free-space, and satellite networks for the future quantum internet.

**COURSE ASSESSMENT**

The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No | Component | Weightage |
|---|---|---|
| 1. | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| 2. | Mid-term examination | 30% |
| 3. | End Semester Examination | 50% |

**COURSE CONTENTS**

**Module 1:**

Basics of Polarization optics, 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 etc.

**(No. of lectures- 9)**

**Module II:**

Digital communication – information theory (basics), Information entropy, Noiseless channel encoding, Noisy channel encoding, No cloning theorem, Quantum Memories, Quantum repeaters, Entanglement and Bell Theorems, Bell Measurements and Tests. **(No. of lectures- 7)**

**Module III:**

Quantum Teleportation protocol, Quantum Dense coding, Introduction to Quantum Key Distribution protocols, Quantum Networks and Quantum Internet. Survey of Hardware implementations, Free space communications, Satellite based communications, Fibre optics-based communications. **(No. of lectures- 10)**

**TEXT/ REFERENCE BOOKS: -**


1. Quantum computation and quantum information – Nielsen and Chuang Cambridge University Press, Cambridge (2010)
2. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015).

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHPXXX | Quantum Technology Lab | 3 | 0 | 0 | 6 | 0 |

## COURSE CONTENTS

**Note: Students need to perform minimum 8 selected experiments**

1. To measure the de Broglie wavelength of the electrons.
2. To study the interference of polarized beams using a Mach-Zehnder-interferometer
3. To study the Single-Photon Interference using Quantum Eraser.
4. To measure sub-shot-noise phase sensitivity in an optical interferometer using squeezed states of light.
5. Quantum Sensing of Magnetic Fields using Nitrogen-Vacancy (NV) Centers in Diamond.
6. To calculate and validate the quality factor of series and parallel RLC circuits using theoretical and experimental data.
7. To observe and quantify the thermal noise generated by resistors at varying temperatures using a spectrum analyser.
8. To study and compare the principles of homodyne and heterodyne signal demodulation techniques.
9. To perform data acquisition and digitization using Analog-to-Digital Converters (ADCs), and to analyse the effects of under-sampling (aliasing), oversampling, and quantization noise on signal reconstruction.
10. To deposit a high-quality thin film of $SrTiO_3$ or $BaTiO_3$ onto a single-crystal substrate using Pulsed Laser Deposition, and to optimize the film thickness by controlling the laser pulse count and repetition rate.
11. To synthesize large-area, high-quality monolayer graphene on a catalytic copper foil substrate via methane decomposition in a thermal CVD furnace.
12. To identify and characterize the layer count, structural defects, and doping levels of exfoliated 2D materials using Raman effect.
13. To fabricate a functional quantum electronic device by patterning source, drain, and gate contacts onto a CVD-grown 2D material using optical lithography and metal evaporation techniques.
14. To study the time-resolved absorption of quantum dots and graphene-based materials.
15. To synthesize and evaluate the electrochemical performance of quantum dot/2D material-based heterostructures as electrodes for high-capacity lithium-ion batteries and supercapacitors.
16. To evaluate the surface roughness, grain size distribution, and step-terrace morphology of a thin film or a transferred 2D material flake using AFM.
17. To simulate a single qubit on the Bloch sphere and visualize the state transformations under the action of Pauli and Hadamard gates using Qiskit.

18. To compute and analyse the electronic band structure of 2D materials using open-source Density Functional Theory (DFT) software.
19. To design, execute, and validate a quantum entanglement circuit on a real cloud-based IBM Quantum processor.
20. To simulate a 2D ferromagnetic Ising model and study its phase transitions using the Metropolis-Hastings algorithm.
21. To solve the time-independent Schrödinger equation for non-trivial potentials using Python-based numerical eigenvalue solvers.
22. To map out the current-voltage characteristics of a superconducting Josephson junction to observe the DC Josephson effect and AC Josephson effect.
23. Measurement & study characteristics of a single photon detection system using Quantum Simulations.

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHPXXX | Quantum Sensing and Metrology | 3 | 3 | 0 | 0 | 0 |

**PREREQUISITE – Basic Quantum Mechanics**

**COURSE OBJECTIVE(s)**

The course aims to provide a foundational understanding of classical and quantum measurement theories, including Cramer-Rao bounds and Fisher information, quantum states of light, tomography, and advanced sensing applications like gravimetry and magnetometry using atomic and spin-based systems for high-precision technologies.

**COURSE ASSESSMENT**

The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No. | Component | Weightage |
|---|---|---|
| 4. | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| 5. | Mid-term examination | 30% |
| 6. | End Semester Examination | 50% |

**COURSE CONTENTS**

**Module 1: Classical Foundations and Sensitivity Limits**

Classical sensing: Photo detection, Classical noise: Johnson Noise, Telegraph noise, flicker or 1/f noise, Sensitivity of classical measurements, Classical Fisher information, Cramer-Rao bounds, Information theory basics. **(No. of lectures- 7)**

**Module II: Quantum Measurement Theory and States of Light**

Quantum measurements: Projective/orthogonal and Approximate/non-orthogonal measurements, Weak continuous measurements, Error-disturbance relations, Standard quantum limits, Quantum non-demolition measurements, States of light: Fock states, Coherent states, and Squeezed states, Tomography, Wigner quasi-probability distribution, P-distribution, and Husimi Q function. **(No. of lectures- 11)**

**Module III: Quantum Detection and Sensing Applications**

Quantum photo detection: Square-law detectors, Intensity measurements, and Photo-detection, Linear Detectors and Quadrature Measurements, Quantum Cramer-Rao bounds, Single photon-based sensing applications, Entanglement based sensing applications, Atomic state-based sensing, Solid-state spin-based sensing applications: Metrology, Gravimetry and Magnetometry. **(No. of lectures- 8)**

**TEXT/ REFERENCE BOOKS: -**


1. Quantum Measurement and Control, Howard Wiseman and David Milburn, Cambridge University Press (2014)
2. Quantum Measurement, Vladimir Braginsky and Farid Ya Khalili, Cambridge University Press (1995)
3. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)

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**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHTXXX | Quantum Materials and Devices | 3 | 3 | 0 | 0 | 0 |

**PREREQUISITE – Basic Quantum Mechanics and Condensed Matter Physics**

**COURSE OBJECTIVE(s)**

The course aims to provide students with a comprehensive understanding of electronic band theory, superconductivity, and magnetism. Students will explore 2D materials like graphene and TMDCs, master the basics of topological phases, and learn practical material growth techniques, including MBE, CVD, and lithography for quantum technology applications.

**COURSE ASSESSMENT**

The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No. | Component | Weightage |
|---|---|---|
| a) | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| b) | Mid-term examination | 30% |
| c) | End Semester Examination | 50% |

**COURSE CONTENTS**

**Module 1: Basics of Material's Physics**

Review of band theory basics: Metals, Semiconductors, and Insulators, Band structure of solids, Correlated systems, Review of magnetism: Para and ferro magnetism basics, Magnetic measurements, Hall effect, and Magnetoresistance, Faraday and Kerr effects. Survey of semiconducting and superconducting devices for quantum technologies (electronic, quantum optical devices and principle of operation). **(No. of lectures- 7)**

**Module II: Superconductivity and Topological Phases**

Superconductivity: BCS theory and Ginzburg Landau theory, Josephson Effect: AC and DC Josephson effects, Survey of superconducting devices for quantum technologies, Basics of Topology, Geometric phases: Berry Phase, Aharonov Bohm effect, Topological phases of matter. **(No. of lectures- 8)**

**Module III: Low-Dimensional Materials and Growth Techniques**

2D materials: Graphene and its properties (single and few layers), Transition Metal Dichalcogenides: Electronic and Optical Properties, Survey of material growth techniques: Molecular beam epitaxy (MBE), Chemical vapor deposition (CVD) and MOVPE, Pulsed laser deposition (PLD), Crystal growth techniques. Materials to devices: lithography for device fabrication. **(No. of lectures- 11)**

**TEXT/ REFERENCE BOOKS: -**

1. Condensed Matter Physics, M P Marder, 2nd Edition, John Wiley and Sons (2010)
2. Introduction to Superconductivity, Michael Tinkham, standard ed., Medtech (2017)
3. Topological Phases of Matter, Roderich Moessner, Joel E. Moore, 1st Edition Cambridge University Press (2021)

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**DEPARTMENT OF PHYSICS**

## DETAILS OF THE COURSE

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHTX XX | **Quantum Optics** | **3** | **2** | **1** | **0** | **0** |

**PREREQUISITE – Basic Quantum Mechanics and Electrodynamics**

## COURSE OBJECTIVE(s)

The course aims to provide a rigorous understanding of electromagnetic field quantization and optical coherence. Students will master phase-space representations, analyze light-matter interactions via the Jaynes-Cummings model to model decoherence for advanced photonic applications.

## COURSE ASSESSMENT

The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No. | Component | Weightage |
|---|---|---|
| 1. | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| 2. | Mid-term examination | 30% |
| 3. | End Semester Examination | 50% |

## COURSE CONTENTS

**Module I: Field Quantization and Optical Coherence**

Electromagnetic field quantization, Number, coherent, and squeezed states, Hanbury-Brown and Twiss experiments (Photon bunching and anti-bunching), Hong-Ou-Mandel interference, Young's double slit experiment and first order coherence, Coherence functions of arbitrary order, Operator ordering (Normal, symmetric, and anti-normal), Interferometry **(No. of lectures- 13)**

**Module II: Phase-Space Representations and Non-Classicality**

Wigner distribution, P-function and the notion of non-classicality with some examples of nonclassical states like squeezed states and their applications, Husimi Q function **(No. of lectures- 6)**

**Module III: Light-Matter Interaction and Open Quantum Systems**

Classical model of light-matter interaction, Semi-classical model of light-matter interaction, Quantum light-matter interaction, Rabi Model, Jaynes-Cummings model, Fermi's golden rule, Born-Markov Lindblad Master Equation. **(No. of lectures- 7)**

## TEXT BOOKS: -

1. Introductory Quantum Optics, Christopher Gerry and Peter Knight, Cambridge University Press (2004)
2. Quantum Optics, D. F. Walls, Gerard J. Milburn, $2^{nd}$ Edition, Springer (2008)

## REFERENCE BOOKS: -

1. Quantum Optics: An introduction, Mark Fox, Oxford University Publishers (2006)
2. Quantum Optics for Beginners, Z. Ficek and M. R. Wahiddin, $1^{st}$ edition, Jenny Stanford Publishing (2014)

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHTXXX | Foundation of Quantum Computation | 3 | 3 | 0 | 0 | 0 |

**PREREQUISITE – None**

**COURSE OBJECTIVE(s)**

- To develop a strong mathematical foundation required for quantum computing, including vector spaces, linear algebra, and Hilbert space formalism.
- To understand the fundamental principles of quantum mechanics relevant to computation, such as qubits, superposition, entanglement, and measurement.
- To introduce quantum operators, gates, and circuit models used in quantum information processing.
- To familiarize students with multi-qubit systems, tensor products, and quantum correlations like entanglement.
- To provide basic knowledge of quantum algorithms and their physical interpretation.
- To enable students to simulate quantum systems using modern tools like Qiskit.
- To understand the impact of noise, decoherence, and errors in practical quantum computing systems.
- To build a foundation for advanced study or research in quantum computing and quantum information science.

**COURSE ASSESSMENT**

The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No. | Component | Weightage |
|---|---|---|
| a) | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| b) | Mid-term examination | 30% |
| c) | End Semester Examination | 50% |

**COURSE CONTENTS**

## Module I: Mathematical Foundation

Vector spaces and complex Hilbert spaces, Dirac notation (bra-ket formalism), Inner products and norms, Linear operators and matrix representation, Eigenvalues and eigenvectors, Unitary and Hermitian operators, Tensor products and composite systems, Basic probability theory and entropy (introductory level), Matrix decomposition. **(No. of lectures: 11)**

## Module II: Physics of Quantum Systems

Qubits and state representation, Measurement postulate and probabilities, Bloch sphere representation, Multi-qubit systems and tensor structure, Quantum entanglement and Bell states, Quantum gates (Pauli, Hadamard, Phase, CNOT), Quantum circuits and unitary evolution, Density matrix formalism (basic introduction), Interaction with environment and decoherence (introductory) **(No. of lectures: 13)**

## Module III: Quantum Computing using Qiskit

Quantum circuit model, Circuit composition and measurement, Basic quantum algorithms (Deutsch, teleportation, superdense coding), Introduction to Qiskit, Building and simulating quantum circuits, Visualization of results, Variational Quantum Eigensolver (introductory concept), Noise and error in quantum systems (basic understanding) **(No. of lectures: 14)**

### Text books

1. Nielsen, M. A., & Chuang, I. L. (2010). *Quantum computation and quantum information* (10th anniversary ed.). Cambridge University Press.
2. Hidary, J. D. (2019). *Quantum computing: An applied approach*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-23922-0
3. Griffiths, D. J., & Schroeter, D. F. (2018). *Introduction to quantum mechanics* (3rd ed.). Cambridge University Press.
4. Zettili, N. (2009). *Quantum mechanics: Concepts and applications* (2nd ed.). John Wiley & Sons.

### Reference Books

1. Javadi-Abhari, A., Treinish, M., Krsulich, K., Wood, C. J., Lishman, J., Gacon, J., Martiel, S., Nation, P., Bishop, L. S., Cross, A. W., Johnson, B. R., & Gambetta, J. M. (2024). *Quantum computing with Qiskit*. arXiv:2405.08810. https://doi.org/10.48550/arXiv.2405.08810
2. IBM Quantum. (2024). *IBM Quantum documentation*. IBM Corporation. https://docs.quantum.ibm.com
3. Bernhardt, C. (2019). *Quantum computing for everyone*. The MIT Press.

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**
**DEPARTMENT OF PHYSICS**

**DETAILS OF THE COURSE**

| Course Type | Course Code | Course Title | Credits | Lecture | Tutorial | Practical | Studio |
|---|---|---|---|---|---|---|---|
| PE | 26PHTXXX | Quantum Computing for Physical Systems | 3 | 2 | 1 | 0 | 0 |

**PREREQUISITE – None**

**COURSE OBJECTIVE(s)**
- To train the UG students about Quantum Computing and Simulations, and compare the results with the classical simulations.
- Bridge the gap between theoretical quantum mechanics and the mathematical framework of quantum computing.
- Implement core quantum algorithms and Hamiltonian-mapping techniques for physical-system simulations.
- Gain hands-on expertise in using Qiskit to solve variational problems (VQE/QAOA) and model real-world problems of Physical systems and modern physics applications.

**COURSE ASSESSMENT**
The Course Assessment (culminating to the final grade), will be made up of the following three components;

| S. No. | Component | Weightage |
|---|---|---|
| a) | Internal assessment (based upon assignments, quizzes and attendance) | 20% |
| b) | Mid-term examination | 30% |
| c) | End Semester Examination | 50% |

**COURSE CONTENTS**
**Module 1: Foundations of Quantum Computing in Physics**
Introduction to quantum computing and limitations of classical computing, Four Postulates of Quantum mechanics, Hilbert Spaces, State Vectors and Dirac notation, Density Matrix, Operators and Matrices: Hermitian, Unitary and Projection operators, Composite systems (Tensor products), Multiparticle Physical system, State in Quantum computing, Single Qubit Gates: Pauli-X, Y, Z, Hadamard (H) and Phase gates (S, T), Multi-Qubit Gates: Controlled-NOT (CNOT) and Controlled-U gates, Universal Quantum Gates, Design and analysis of basic quantum circuits and the concept of "Quantum Parallelism" in solving the combinatorial optimization problem in Physics. **(No. of lectures: 14)**

**Module 2: Quantum Algorithms & Tools for Quantum Simulations**
SparsePauliOp: Decomposing complex Hamiltonians into weighted sums of Pauli strings (X, Y, Z, I), Fermionic-to-Qubit Mapping: The necessity of mapping, Jordan-Wigner (JW) Mapping, Bravyi-Kitaev (BK) Mapping, Parity Mapping, Binary mapping, Initial Quantum algorithms: Quantum parallelism, Deutsch's algorithm, The Deutsch–Jozsa algorithm, Quantum Phase Estimation (QPE), Introduction to Variational Algorithms (eg. VQE, QAOA etc), Hamiltonian Simulation Theory: Trotter-Suzuki Decomposition: Approximating $e^{-iHt}$ for non-commuting operators. **(No. of lectures: 14)**

**Module 3: Qiskit Implementation for Physics Problems**

Gates and simple & complex circuits for Physical systems, Variational Algorithms in Practice: VQE (Variational Quantum Eigensolver): Implementation using Ansatz circuits (like RealAmplitudes or EfficientSU2), Optimising parameters using classical routines (COBYLA, SLSQP), Dynamics and Evolution, using qiskit_algorithms. QUBO, QAOA for various applications, Simulating real-world conditions using FakeBackend. Trotterization using Pauli Evolution Gate. **(No. of lectures: 11)**

## Textbooks


1. Nielsen, M. A., & Chuang, I. L. (2010). *Quantum Computation and Quantum Information* (10th Anniversary ed.). Cambridge University Press.
2. Zettili, N. (2009). *Quantum mechanics: Concepts and applications* (2nd ed.). John Wiley & Sons.
3. Kaye, P., Laflamme, R., and Mosca, M. (2007). *An Introduction to Quantum Computing*. Oxford University Press.


## References


1. Asfaw, A., Bello, L., Müller, M., Marquardt, F., & Siraichi, L. (2022). *Qiskit Pocket Guide: Swift Machine Learning with Quantum Computing*. O'Reilly Media.
2. Bernhardt, C. (2019). *Quantum Computing for Everyone*. MIT Press.
3. Combarro, E. F., & González-Castillo, S. (2023). *A Practical Guide to Quantum Computing with Qiskit*. Packt Publishing.
4. Griffiths, D. J., & Schroeter, D. F. (2018). *Introduction to Quantum Mechanics* (3rd ed.). Cambridge University Press.
5. Hidary, J. D. (2019). *Quantum Computing: An Applied Approach*. Springer.
6. IBM Quantum. (2026). *Qiskit Documentation*. https://docs.quantum.ibm.com/