Minor Degree in Quantum Technology
(for B. Tech. students)

Structure of the program

<table>
<tr><th rowspan="3">Courses</th><th colspan="6">Credits</th><th rowspan="3">Total credits</th></tr>
<tr><th>1st year</th><th>2nd year</th><th colspan="2">3rd year</th><th colspan="2">4th year</th></tr>
<tr><th>1st & 2nd Sem.</th><th>3rd & 4th Sem.</th><th>5th Sem.</th><th>6th Sem.</th><th>7th Sem.</th><th>8th Sem.</th></tr>
<tr><td>Minor Programme Electives</td><td>-</td><td>-</td><td>04</td><td>08</td><td>04</td><td>-</td><td>16</td></tr>
<tr><td>Summer Training/ Independent Study/Project</td><td>-</td><td>-</td><td>-</td><td>-</td><td>02*</td><td>-</td><td>02</td></tr>
<tr><td>Total</td><td>-</td><td>-</td><td>04</td><td>08</td><td>06</td><td></td><td>18</td></tr>
</table>

(* During the summer vacation after 6th semester)

List of Courses

<table>
<tr><th>Semester</th><th>Course Code</th><th>Course Name</th><th>L</th><th>T</th><th>P</th><th>Credits</th></tr>
<tr><td>5th (Mandatory)</td><td>PHBB301</td><td>Introduction to Quantum Technologies and Applications</td><td>3</td><td>0</td><td>2</td><td>4</td></tr>
<tr><td>6th (Mandatory)</td><td>PHBB351</td><td>Quantum Science and Technology</td><td>3</td><td>0</td><td>2</td><td>4</td></tr>
<tr><td rowspan="2">6th (Select anyone)</td><td>PHLB352</td><td>Introduction to Quantum Materials and Devices</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td>PHLB353</td><td>Solid State Physics for Quantum Technologies</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td rowspan="5">7th (Select anyone)</td><td>PHLB401</td><td>Introduction to Quantum Computation</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td>PHLB402</td><td>Introduction to Quantum Communication</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td>PHLB403</td><td>Introduction to Quantum Sensing</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td>PHLB404</td><td>Quantum Optics</td><td>3</td><td>1</td><td>0</td><td>4</td></tr>
<tr><td>PHPB405</td><td>Summer Training/ Independent Study/Project</td><td>-</td><td>-</td><td>-</td><td>2</td></tr>
</table>

COURSE CONTENT

Course Title:	**Introduction to Quantum Technologies and Applications**
Course Code:	**PHBB301**
L-T-P:	**3-0-2**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:		**Cognitive Levels**
CO-1	Explain the general physical principles involved in realizing qubits for quantum computation.	Understand (Level-II)
CO-2	Identify and compare various hardware implementations of qubits used in quantum computing.	Analyze (Level-IV)
CO-3	Describe the fundamental concepts and working principles of quantum sensing and its practical relevance.	Understand (Level-II)
CO-4	Analyze real-world applications of quantum sensing and understand the implementation of quantum communication protocols in fibre-based and free-space systems.	Analyze (Level-IV)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	2	–	–	–	3	–	–	–	–	–	–	–		
CO-3	2	–	–	–	3	–	–	–	–	–	–	–		
CO-4	2	2	–	–	3	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Quantum Technologies – four verticals, Motivation for Quantum Technologies, A qualitative overview of salient aspects of quantum physics: Quantum States, Wavefunctions, Probabilistic interpretation, Physical observables, Hermitian operators, expectation values, Heisenberg uncertainty principle, Schrodinger equation, Time	06

	evolution distinction from classical physics Heuristic description of Superposition, Tunnelling and entanglement, No cloning theorem, Simulating classical systems – Feynman's idea of a quantum simulator and the birth of the field	
Module-III	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), 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 qubitsConventional NMR qubits, NV centres, Overview of applications and recent achievements, RSA and Shor's algorithm, Quantum Advantage, Long term goals and strategies being followed, Error correction	10
Module-IV	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
Module V	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

Learning Resources:

Text Books:	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:	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)
Other Suggested Readings:	1. Quantum computing explained, David McMahon, Wiley (2008)
List of Experiments:	

1.	Creating and Measuring Quantum Superposition States in Qubits
2.	Generating and Measuring Entangled Bell States Using Two Qubits
3.	Simulating Classical System Behavior Using Quantum Circuits Based on Feynman's Quantum Simulator Concept
4.	Understanding Qubits and Quantum Gates
5.	Quantum Circuit with CNOT Gate for Entanglement
6.	Simulating a Simple Quantum Algorithm (Shor's Algorithm)
7.	Implementing Quantum Error Correction
8.	Basic Quantum Magnetometry (Simulating a Magnetic Field Interaction)
9.	Ramsey Interferometry: Measuring Quantum Phase Shifts and Coherence in Qubits Using Rotational Pulses
10.	Quantum Key Distribution (QKD) Using BB84 Protocol

Course Title:	**Quantum Science and Technology**
Course Code:	**PHBB351**
L-T-P:	**3-0-2**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics PHBB301–Introduction to Quantum Technologies and Applications

Course Outcomes:		**Cognitive Levels**
CO1	Understand and apply basic mathematical tools used in quantum science.	Apply (Level-III)
CO2	Explain the key postulates of quantum mechanics and their simple applications.	Understand (Level-II)
CO3	Describe the basic ideas of statistical physics and information science relevant to quantum systems.	Understand (Level-II)
CO4	Understand basic concepts of computational complexity and their connection to quantum computing.	Understand (Level-II)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	2	–	–	–	–	–	–	–		
CO-2	3	–	–	–	2	–	–	–	–	2	–	–		
CO-3	2	–	–	–	3	–	–	–	–	–	–	2		
CO-4	2	2	–	–	2	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Quantum Mechanics: Brief overview of classical physics (This segment is meant for the student to understand what a Hamiltonian is, which will feature later in quantum mechanics), Hamiltonian function and Hamilton's equations, Phase-space description of a system, Connection and Equivalence with Newton's laws for simple systems – free particle, particle moving in a conservative potential, examples of Harmonic oscillator,	16

	hydrogen atom, Historical evolution of quantum mechanics, Planck's quantum hypothesis, Photo electric effect, Atomic spectra, Bohr's quantisation principle, De Broglie's Wave particle duality, Postulates of Quantum Mechanics, 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, Heisenberg's Uncertainty principle, Density operator formalism of quantum mechanics – pure and mixed states, Superposition and Entanglement in quantum mechanics, No cloning theorem, Applications of postulates –Particle in a box, Hydrogen atom, Harmonic Oscillator, Number states, ladder operators and Coherent states of a harmonic oscillator, Spin and Angular momentum – spin half particles, Rabi problem of a spin-half particle in a rotating magnetic field, Bosons and Fermions.	
Module-II	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	8
Module-III	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	6
Module-IV	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)	6

Learning Resources:

Text Books:	1. Introduction to Quantum Mechanics, Griffiths D. J., 3rd Edition, Cambridge University Press (2024) 2. Introduction to Electrodynamics, Griffiths D. J., 4th edition, Cambridge University Press (2020)

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

List of Experiments:	
1.	Diffraction Analysis with Single Slit and Diffraction Grating
2.	Characterization of Polarization Optics
3.	Resonance in Series and Parallel RLC Circuits
4.	Measurement of Intrinsic Losses in RLC Circuits
5.	Design and Testing of Basic Digital Circuits
6.	Measurement of S-parameters for 2-port and 3-port RF Networks
7.	Running Quantum Algorithms on Simulators

Course Title:	Introduction to Quantum Materials and Devices
Course Code:	**PHLB 352**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:		**Cognitive Levels**
CO1	Understand the basic concepts of quantum materials and their unique properties.	Understand (Level-II)
CO2	Explain the fundamentals of band theory in solids and its role in understanding material behavior.	Understand (Level-II)
CO3	Describe the basic principles of magnetism and superconductivity in materials.	Understand (Level-II)
CO4	Discuss emerging 2D materials like graphene and TMDCs and understand the basics of topology and topological phases of matter.	Understand (Level-II)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	3	–	–	–	2	–	–	–	–	–	–	–		
CO-3	3	2	–	–	–	–	–	–	–	–	–	–		
CO-4	2	2	–	–	2	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Band Theory and Semiconducting Devices: 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)	08
Module-II	Magnetism and Correlated Systems: Correlated systems, Magnetism, Para, ferro magnetism basics, Magnetic measurements, hall effect, magnetoresistance, Faraday and Kerr effects	08

Module-III	Superconductivity and Quantum Devices: Superconductivity, BCS theory, Ginzburg Landau, Josephson Effect – AC and DC Josephson effects, Survey of superconducting devices for quantum technologies	08
Module-IV	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	12

Learning Resources:

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

Course Title:	**Solid State Physics for Quantum Technologies**
Course Code:	**PHLB 353**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:		**Cognitive Levels**
CO1	Understand the basic concepts of solid-state physics.	Understand (Level-II)
CO2	Explain different approximations used to describe electronic states in solids.	Analyze (Level-IV)
CO3	Describe the theory of phonons and their role in the properties of solids.	Apply (Level-III)
CO4	Understand the basic theories of magnetism and superconductivity in solid materials.	Analyze (Level-IV)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	3	2	–	–	2	–	–	–	–	–	–	–		
CO-3	3	2	–	–	–	–	–	–	–	–	–	–		
CO-4	3	2	–	–	–	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Crystal Structure and Bonding in Solids: 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	08
Module-II	Electron Theory of Solids: The Drude theory of metals, DC & AC electrical conductivity of a metal, Hall effect & magnetoresistance, Density of states,	08

	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	
Module-III	Lattice Vibrations and Phonons: 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	09
Module-IV	Magnetism in Solids: Magnetism, Dia-, Para-, and Ferromagnetism, Langevin's theory of paramagnetism, Weiss Molecular theory	05
Module V	Superconductivity: 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	06

Learning Resources:

Text Books:	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)
Reference Books:	1. Introduction to Superconductivity, Michael Tinkham, standard edition, Medtech (2017)
Other Suggested Readings:	

Course Title:	**Introduction to Quantum Computation**
Course Code:	**PHLB 401**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics CSBB 181/CSVB 204 - Problem Solving and Computer Programming

Course Outcomes:		**Cognitive Levels**
CO1	Understand the basic postulates of quantum mechanics and the theoretical foundation of qubits and their physical implementations.	Understand (Level-II)
CO2	Use density operators and explain time evolution in mixed quantum states.	Apply (Level-III)
CO3	Describe the basic ideas of quantum gates and how they are used in quantum circuits.	Understand (Level-II)
CO4	Explain the working principles of key quantum algorithms and the basic concepts of quantum error correction.	Analyze (Level-IV)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	2	–	–	–	–	–	–	–		
CO-2	2	–	–	–	3	–	–	–	–	–	–	2		
CO-3	2	–	2	–	3	–	–	–	–	–	–	–		
CO-4	2	2	–	–	3	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Foundations of Quantum Information: 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	09
Module-II	Classical Computation and Reversibility:	09

	Review of Turing machines and classical computational complexity, Time and space complexity (P, NP, PSPACE), Reversible computation, Universal quantum logic gates and circuits	
Module-III	Core Quantum Algorithms: 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 – Q, EQP, BQP, BPP, QMA, Additional Topics in Quantum Algorithms, Variational Quantum Eigensolver (VQE), HHL,QAOA	10
Module-IV	Quantum Error Correction and the NISQ: Introduction to Error correction, Fault-tolerance, Simple error correcting codes, Survey of current status, NISQ era processors, Quantum advantage claims, Roadmap for future	08

Learning Resources:

Text Books:	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:	1. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015) 2. Quantum error correction and Fault tolerant computing, Frank Gaitan, 1st edition, CRC Press (2008)
Other Suggested Readings:	1. Quantum computing explained, David McMahon, Wiley (2008) 2. Introduction to Quantum Computing: From a lay person to a programmer in 30 steps, Hui Yung Wong, 1st edition, Springer-Nature Switzerland AG (2022)

Course Title:	**Introduction to Quantum Communication**
Course Code:	**PHLB 402**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:

CO-1	Understand the basic concepts of electromagnetic (EM) theory.
CO-2	Explain the basic principles of photodetection and how light is measured.
CO-3	Describe the basic ideas of information theory relevant to communication.
CO-4	Understand the main concepts used in quantum communication systems.

Course Outcomes:		**Cognitive Levels**
CO1	Understand the basic concepts of electromagnetic (EM) theory.	Understand (Level-II)
CO2	Explain the basic principles of photodetection and how light is measured.	Apply (Level-III)
CO3	Describe the basic ideas of information theory relevant to communication.	Analyze (Level-IV)
CO4	Understand the main concepts used in quantum communication systems.	Understand (Level-II)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	2	–	–	–	3	–	–	–	–	–	–	–		
CO-3	2	2	–	–	2	–	–	–	–	–	–	–		
CO-4	2	2	–	–	3	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Basics of Polarization Optics and Detection: Basics of Polarization optics, Quarter and half-wave plates, Polarizing beam splitters, Basics of linear and square-law detectors, Quadrature amplitude modulation, Heterodyne	09

	and Homodyne demodulation and linear detectors, Intensity measurements and square law detectors. Photomultipliers, Avalanche Photo diodes	
Module-II	Digital Communication and Information Theory: Digital communication – information theory (basics), Information entropy, Noiseless channel encoding, Noisy channel encoding. Core Quantum Information Concepts: No cloning theorem, Quantum Memories, Quantum repeaters, Entanglement and Bell Theorems, Bell Measurements and Tests	12
Module-IV	Quantum Communication Protocols: Quantum Teleportation protocol, Quantum Dense coding, Quantum Key Distribution protocols, BB84, E91, BBM92, B92, COW, DPS	07
Module V	Quantum Networks and Implementation: Quantum Networks and Quantum Internet, Survey of Hardware implementations, Free space communications, Satellite based communications, Fibre optics-based communications	08

Learning Resources:

Text Books:	1. Quantum computation and quantum information – Nielsen and Chuang Cambridge University Press, Cambridge (2010)
Reference Books:	1. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)
Other Suggested Readings:	

Course Title:	**Introduction to Quantum Sensing**
Course Code:	**PHLB 403**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:		**Cognitive Levels**
CO1	Understand the basic principles of classical sensing and how they compare with quantum sensing.	Understand (Level-II)
CO2	Explain key aspects of quantum measurement and how quantum states are measured.	Apply (Level-III)
CO3	Describe how quantum sensing is quantified and how it differs from classical methods.	Analyze (Level-IV)
CO4	Discuss the applications of quantum sensing and how measurements of quantum states of light are performed.	Analyze (Level-IV)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	3	–	–	–	3	–	–	–	–	–	–	–		
CO-3	2	2	–	–	3	–	–	–	–	–	–	–		
CO-4	2	2	–	–	3	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Fundamentals of Classical Sensing and Noise: Classical sensing, Photo detection, Classical noise, Johnson Noise, Telegraph noise, flicker or 1/f noise Sensitivity and Information Theory in Classical Measurements: Sensitivity of classical measurements, Classical Fisher information, Cramer - Rao bounds	10
Module-II	Quantum Measurement Techniques: Quantum measurements, projective/orthogonal measurements, Approximate/non-orthogonal	08

	measurements, Weak continuous measurements, Error-disturbance relations, Standard quantum limits, Quantum non-demolition measurements	
Module-IV	Quantum States of Light and Their Characterization: States of light, Fock states, Coherent states, Squeezed states, Tomography, Wigner quasi-probability distribution, P-distribution, Husimi Q function	08
Module V	Quantum Detection and Sensitivity Limits: Quantum photo detection, Square-law detectors, Intensity measurements and Photo-detection, Linear Detectors and Quadrature Measurements, Quantum Cramer-Rao bounds Quantum Sensing Applications: Single photon-based sensing applications, Entanglement based sensing applications, Atomic state-based sensing, solid-state spin-based sensing applications (gravimetry, magnetometry)	10

Learning Resources:

Text 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)
Reference Books:	1. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
Other Suggested Readings:	

Course Title:	**Quantum Optics**
Course Code:	**PHLB 404**
L-T-P:	**3-1-0**
Credits:	**4**
Pre-requisites:	PHBB101 – Engineering Physics

Course Outcomes:		**Cognitive Levels**
CO1	Understand the quantization of the electromagnetic field and different representations of states of light.	Understand (Level-II)
CO2	Explain key experimental techniques used in photonics.	Apply (Level-III)
CO3	Describe classical, semi-classical, and quantum models of light-matter interaction.	Analyze (Level-IV)
CO4	Model decoherence in quantum systems using the Master equation approach.	Apply (Level-III)

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2
CO-1	3	2	–	–	–	–	–	–	–	–	–	–		
CO-2	2	–	–	2	3	–	–	–	–	–	–	–		
CO-3	3	2	–	–	–	–	–	–	–	–	–	–		
CO-4	3	–	–	2	2	–	–	–	–	–	–	–		

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:		
Module	**Detailed Syllabus**	**Contact Hours**
Module-I	Quantization of the electromagnetic field: Number states, coherent states, squeezed states, Hanbury-Brown and Twiss experiments – Photon bunching, Photon anti bunching, Hong-Ou-Mandel interference	09
Module-II	Theory of Optical coherence: Young's double slit experiment and first order coherence, Coherence functions of arbitrary order, Normal ordering, symmetric ordering and ani-normal ordering of operators, Interferometry	8

Module-III	Phase-space representations of states of light: 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	8
Module-IV	Light-matter interaction: Classical model of light-matter interaction, Semi-classical model of light-matter interaction, Quantum light-matter interaction, Rabi Model, Jayne's-cummings model Open quantum systems: Fermi golden rule, Born-Markov Lindblad Master Equation	11

Learning Resources:

Text Books:	1. Introductory Quantum Optics, Christopher Gerry and Peter Knight, Cambridge University Press (2004)
Reference Books:	1. Quantum Optics, D. F. Walls, Gerard J. Milburn, 2nd Edition, Springer (2008) 2. Quantum Optics: An introduction, Mark Fox, Oxford University Publishers (2006)
Other Suggested Readings:	1. Quantum Optics for Beginners, Z. Ficek and M. R. Wahiddin, 1st edition, Jenny Stanford Publishing (2014)

<table>
<tr><td>Course Code</td><td colspan="5">PHPB405</td></tr>
<tr><td>Course Title</td><td colspan="5">Summer Training/ Independent Study/Project</td></tr>
<tr><td>Type of Course</td><td colspan="5">Project</td></tr>
<tr><td rowspan="2"></td><td>Lecture</td><td>Tutorial</td><td>Practical</td><td>Credits</td><td>Total Lab Hours</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>2</td><td>-</td></tr>
<tr><td>Contact Hours</td><td colspan="5"></td></tr>
<tr><td>Pre-requisite</td><td colspan="5">Nil</td></tr>
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<tr><td colspan="6">Summer Training/ Independent Study/Project related to Quantum Technologies</td></tr>
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