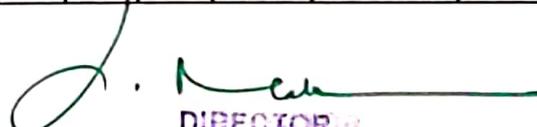


CSE

**SCHOOL OF ENGINEERING AND TECHNOLOGY
SRI PADMAVATI MAHILA VISVAVIDYALAYAM
SCHEME OF INSTRUCTION AND EVALUATION OF B.TECH (Common to all Departments)
R23 REGULATIONS
Minors/Honors in Quantum Technologies**

THEORY															
S.No		Course Code	Course Title	Hours per Week			Credits	Evaluation						Total Marks	
				Internal (30 Marks)						External (70 Marks)					
				Assignment	Objective Test			Subjective Test							
L	T	P	Max. Marks	Duration (min)	Max. Marks	Duration (min)	Max. Marks	Duration (hrs)	Max. Marks						
1	Mandatory	23QTT01	Survey of Quantum technologies and Applications	3	0	0	3	5	20	10	90	15	3	70	100
2		23QTT02	Foundations of Quantum Technologies	3	0	0	3	5	20	10	90	15	3	70	100
3	At least one is Mandatory	23QTT03	Basic Programming	2	0	0	2	5	20	10	90	15	3	70	100
4		23QTT04	Basics for Quantum Technologies	2	0	0	2	5	20	10	90	15	3	70	100
5	At least one is Mandatory	23QTT05	Introduction to Quantum Computation	3	0	0	3	5	20	10	90	15	3	70	100
6		23QTT06	Introduction to Quantum Communication	3	0	0	3	5	20	10	90	15	3	70	100
7		23QTT07	Introduction to Quantum Sensing	3	0	0	3	5	20	10	90	15	3	70	100
8		23QTT08	Introduction to Quantum Materials	3	0	0	3	5	20	10	90	15	3	70	100
9	Optional/ Additional Courses	23QTT09	Engineering Foundations of Quantum Technologies	3	0	0	3	5	20	10	90	15	3	70	100
10		23QTT10	Solid State Physics for Quantum Technologies	3	0	0	3	5	20	10	90	15	3	70	100
11		23QTT11	Quantum Optics	3	0	0	3	5	20	10	90	15	3	70	100
PRACTICALS															
S.No	Course Type	Course Code	Course Title	Hours per Week			Credits	Evaluation					Total Marks		
				Internal (30 Marks)					External (70 Marks)						
				Continuous	Test										
L	T	P	Max. Marks	Duration (hrs)	Max. Marks	Duration (hrs)	Max. Marks								
12	At least one is Mandatory	23QTP01	Basic Programming Lab	0	0	2	1	15	2	15	3	70	100		
13		23QTP02	Basic Laboratory Course for Quantum Technologies	0	0	2	1	15	2	15	3	70	100		


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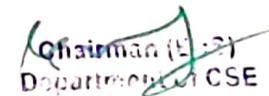
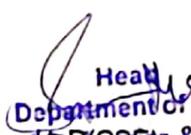

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Table of Courses

Course code	Title	Credits (Theory: Lab)
QT 01 and QT 02 are both Mandatory		
23QTT01	Survey of Quantum technologies and Applications	3:0
23QTT02	Foundations of Quantum Technologies	3:0
At least one of QT 03 and QT 04 is Mandatory		
23QTT03	Basic Programming Lab	2:1
23QTT04	Basic Laboratory Course for Quantum Technologies	2:1
At least one of QT 05, QT 06, QT 07, QT 08 is Mandatory		
23QTT05	Introduction to Quantum Computation	3:0
23QTT06	Introduction to Quantum Communication	3:0
23QTT07	Introduction to Quantum Sensing	3:0
23QTT08	Introduction to Quantum Materials	3:0
Optional / Additional Courses		
23QTT09	Engineering Foundations of Quantum Technologies	3:0
23QTT10	Solid State Physics for Quantum Technologies	3:0
23QTT11	Quantum Optics	3:0

Prerequisites for all courses: Engineering Mathematics (Linear Algebra, Complex algebra, basics of 2nd of ODEs and initial value problems, 2nd order PDEs and boundary value problems, Probability and Statistics, Random variables). Maxwell's equations and EM theory at the level of the core physics syllabus from AICTE model curriculum.

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23QTT01: Survey of Quantum Technologies and Applications (Mandatory)

Credits-3
L:T:P::3:0:0

Sessional Marks: 30
University Marks:70

Course Objectives:

1. Understand basic quantum principles like superposition, entanglement, and the Schrödinger equation.
2. Learn about qubits, quantum gates, and physical implementations of quantum computers.
3. Explore quantum algorithms, quantum advantage, and error correction techniques.
4. Understand quantum sensing concepts and their applications in precise measurements.
5. Learn basics of quantum communication and its use in secure information transfer.

Course Outcomes:

Students of this course learn:

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

UNIT – I

Quantum Technologies: 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 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

UNIT – II

Quantum Computation: Basics of qubits, Review of classical logic gates, Di Vincenzo criteria for realising qubits, Basics of qubit gates and quantum circuits, Physical implementation of qubits – Solid State Qubits: Semiconducting Qubits – quantum dots, spins, Superconducting Qubits – charge, flux and phase, Topological Qubits – proposals and advantages, Atoms and Ions: Trapped ions, Rydberg atoms Neutral atoms, Photonic Qubits: Conventional linear optical setups, Integrated Photonics, NMR qubits: Conventional NMR qubits, NV centres

UNIT – III

Overview of applications and recent achievements: RSA and Shor's algorithm, Quantum Advantage, Long term goals and strategies being followed: Error correction

UNIT – 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

UNIT – V

Quantum Communications: Basics of digital communication, Quantifying classical information – Shannon entropy, Basic ideas of quantum communication, security, eavesdropping, Overview of quantum

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communication achievements: Terrestrial – fibre-based, Free space, Satellite-based

Course References:

1. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
2. Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
3. Elements of Quantum Computation and Quantum Communication, A. Pathak, Boca Raton, CRC Press (2015)
4. An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca, Oxford University Press (2006)
5. Quantum computing explained, David McMahon, Wiley (2008)

Course Outcomes–Program Outcomes–Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	-	-	-	-	-	-	-	-	M	H	-	-
CO2	H	H	M	-	M	-	-	-	-	-	-	H	H	M	M
CO3	H	M	-	M	M	-	-	-	-	-	-	H	H	M	M
CO4	H	H	M	M	H	-	-	-	-	-	-	H	H	H	H
CO5	H	H	H	-	H	-	-	-	L	L	-	H	H	H	H

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**23QTT02: Foundations of Quantum Technologies,
(Mandatory)**

**Credits-3
L:T:P::3:0:0**

**Sessional Marks: 30
University Marks:70**

Course Objectives:

1. To understand the classical foundations of mechanics and their connection to quantum systems like the harmonic oscillator and hydrogen atom.
2. To learn the historical development, core postulates, and mathematical framework of quantum mechanics.
3. To study quantum states using density operators, and explore applications such as entanglement, spin systems, and harmonic oscillators.
4. To understand thermodynamic principles and apply quantum statistical distributions to systems of Bosons and Fermions.
5. To explore the fundamentals of quantum information, decoherence, and computational complexity, including quantum and post-quantum computing classes

Course Outcomes:

Students of this course learn

1. The most relevant mathematical techniques
2. Basic postulates of quantum mechanics and applications
3. Basics of Statistical Physics
4. Basics of Information Science
5. Basics of computational complexity

UNIT – I

Quantum Mechanics: Brief overview of classical physics: 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, hydrogen atom

UNIT – II

Historical evolution of quantum mechanics: Planck's quantum hypothesis, Photo electric effect, Atomic spectra, Bohr's quantization 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

UNIT – III

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

UNIT – IV

Statistical Physics: Quick review of first and second laws of thermodynamics, The Boltzmann Equilibrium and

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Gibbs principle, Applying Gibbs principle to Classical and Quantum harmonic oscillators, Bosons and Fermions and Quantum statistics – Fermi-Dirac and Bose- Einstein distributions

UNIT – V

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

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

Course References:

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

CourseOutcomes–ProgramOutcomes–ProgramSpecificOutcomes(CO-PO-PSO)Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO 7	PO 8	PO 9	PO10	PO11	PO12	PSO1	PSO2	PSO 3
CO1	H	M	-	-	-	-	-	-	-	-	-	H	H	M	-
CO2	H	H	-	M	M	-	-	-	-	-	-	H	H	M	-
CO3	H	M	-	M	-	-	-	-	-	-	-	H	M	M	-
CO4	M	H	M	-	H	-	-	-	-	-	-	H	H	H	-
CO5	H	H	M	-	H	-	-	-	-	-	-	H	H	H	-

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23QTT03: Basic Programming Lab
(Out of QT 03 and QT 04, at least ONE is mandatory)

Credits-3
L:T:P::2:0:2

Sessional Marks: 30
University Marks:70

Course Objectives :

1. To develop foundational coding skills, data structures, and algorithm design with performance benchmarking.
2. To apply numerical methods for solving ordinary and partial differential equations relevant to physical systems.
3. To implement numerical linear algebra methods like matrix inversion, eigenvalue problems, and SVD.
4. To use computational techniques for statistical analysis, random sampling, and Monte Carlo simulations.
5. To apply numerical methods to quantum mechanical and electromagnetic systems using real-world models.

Course outcomes:

Students of this course learn

1. Basics of programming
2. To write programs to solve scientific problems
3. Techniques for scientific computing
4. Applications to quantum mechanics and electromagnetism

UNIT – I

Basics of programming: Data structures, classes, Object-oriented programming, Data storage and retrieval, Memory allocation, Scientific plotting, documentation of codes. Simple algorithms and benchmarking run time: Sorting, Searching, Arithmetic algorithms like GCD, Prime factorization

UNIT – II

Numerical Integration and differential equations: Linear 2nd Order ODEs with constant coefficients, Linear 2nd order ODEs with variable coefficients, Boundary value problems: Poisson equation, Laplace equation, Wave equation, Diffusion Equation

UNIT – III

Numerical techniques in linear algebra: Matrix inverse, Eigenvalue problem, Diagonalisation of matrices, Singular value decomposition

UNIT – IV

Numerical techniques in Probability and Statistics: (Pseudo) Random number generation, Computing statistical moments for data samples, Least Squares fitting, Error Analysis, Hypothesis Testing, Monte Carlo sampling

UNIT – V

Applications to Quantum Mechanics: Eigen energies of coupled two level systems, Eigen energies of two-level system coupled to oscillator (Jaynes-Cummings Model), Driven two-level system – Rabi Problem, Driven damped oscillator – coherent states

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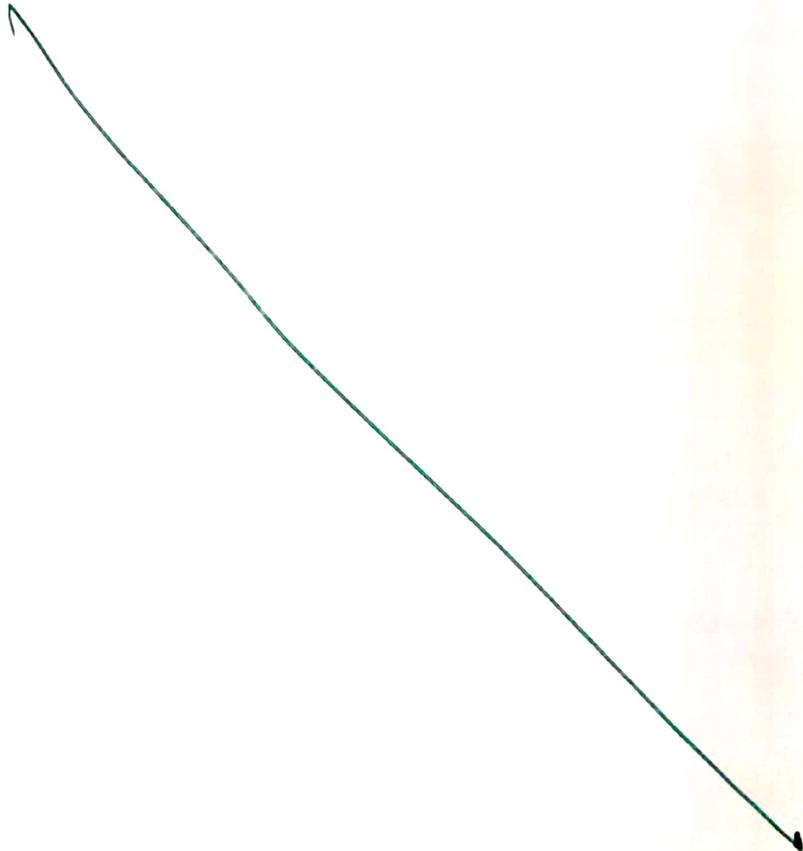
Applications to EM theory: Electrostatic charge distributions, Magnetostatic current distributions, Finite Element techniques for electromagnetic simulations

Course References:

1. Computational Physics, Nicholas Giordano, Hisao Nakanishi, 2nd edition, Pearson-Addison Wesley (2005)

Course Outcomes–Program Outcomes–Program Specific Outcomes (CO-PO-PSO) Mapping

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



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Credits – 2
L:T:P: 2:0:0

23QTT03: Basic Programming

Sessional Marks: 30
University Marks: 70

Course Objectives

To expose the students to the following:

1. To develop foundational coding skills, data structures, and algorithm design with performance benchmarking.
2. To apply numerical methods for solving ordinary and partial differential equations relevant to physical systems.
3. To implement numerical linear algebra methods like matrix inversion, eigenvalue problems, and SVD.
4. To use computational techniques for statistical analysis, random sampling, and Monte Carlo simulations.
5. To apply numerical methods to quantum mechanical and electromagnetic systems using real-world models.

Course outcomes

After successful completion of course, the student should be able to

- CO1. Basics of programming
- CO2. To write programs to solve scientific problems
- CO3. Techniques for scientific computing
- CO4. Applications to quantum mechanics and electromagnetism
- CO5. Able to apply quantum and electromagnetic principles to analyze two-level coupled systems

UNIT – I

Basics of programming: Data structures, classes, Object-oriented programming, Data storage and retrieval, Memory allocation, Scientific plotting, documentation of codes. Simple algorithms and benchmarking run time: Sorting, Searching, Arithmetic algorithms like GCD, Prime factorization

UNIT – II

Numerical Integration and differential equations: Linear 2nd Order ODEs with constant coefficients, Linear 2nd order ODEs with variable coefficients, Boundary value problems: Poisson equation, Laplace equation, Wave equation, Diffusion Equation

UNIT – III

Numerical techniques in linear algebra: Matrix inverse, Eigenvalue problem, Diagonalization of matrices, Singular value decomposition

UNIT – IV

Numerical techniques in Probability and Statistics: (Pseudo) Random number generation, Computing statistical moments for data samples, Least Squares fitting, Error Analysis, Hypothesis Testing, Monte Carlo sampling



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UNIT – V

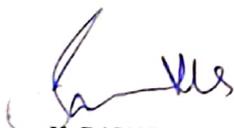
Applications to Quantum Mechanics: Eigen energies of coupled two level systems, Eigen energies of two-level system coupled to oscillator (Jaynes-Cummings Model), Driven two-level system – Rabi Problem, Driven damped oscillator — coherent states
 Applications to EM theory: Electrostatic charge distributions, Magnetostatic current distributions, Finite Element techniques for electromagnetic simulations

Course References:

1. Computational Physics, Nicholas Giordano, Hisao Nakanishi, 2nd edition, Pearson- Addison Wesley (2005)

Course Outcomes–Program Outcomes–Program Specific Outcomes (CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	-	H	-	-	-	-	-	-	M	H	H	-
CO2	H	H	M	M	H	-	-	-	-	-	-	H	H	H	-
CO3	H	H	M	M	H	-	-	-	-	-	-	H	H	M	-
CO4	H	H	-	M	M	-	-	-	-	-	-	H	M	H	-
CO5	M	-	H	-	H	-	-	-	-	M	-	H	M	H	-


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Course Objectives

To expose the students to the following:

1. Learn basics of classical and quantum algorithms.
2. Understand solving quantum/physical differential equations.
3. Build knowledge of matrices and operators used in quantum mechanics.
4. Apply probability, statistics, and numerical methods in quantum systems.
5. To study coupled and quantum oscillators by determining the spring constant and analyzing how relaxation affects Rabi oscillations and transition probabilities.

Course Outcomes

After successful completion of course, the student should be able to

- CO1. Implement classical algorithms and basic Qiskit programs.
- CO2. Solve Schrödinger, wave, and Laplace equations using mathematical methods.
- CO3. Compute eigenvalues, operator inverses, and analyze entanglement.
- CO4. Calculate measurement statistics, run Monte-Carlo simulations, and fit data.
- CO5. Able to analyze coupled classical and quantum two-level systems by determining coupling constants, relating probability oscillations to energy-level splittings

LIST OF EXPERIMENTS

1. Write a program to implement Linear search with the given data set [34,17,19,56,42]. The target element is 19.
2. Write a program to implement selection sort with the given array of elements [5,1,3,4,6,2]
3. Write a program to implement shor's algorithm using QISKIT
4. The time independent Schrodinger equation for harmonic oscillator is $\frac{d^2\psi}{dx^2} = (x^2 - 2E)\psi$. Explain how numerical shooting method is used to estimate ground state energy E_0 .
5. A tightly stretched string with fixed end points $x=0$ and $x=l$ is initially in a position given by $y=y_0 \sin^3 \frac{\pi x}{l}$. If it is released from rest find the displacement $y(x, t)$.
6. Solve Laplace equation $\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0$ with boundary conditions $u(0, y) = 0, u(b, y) = 0 \quad \forall y \quad U(x, 0) = u_0$ for $0 < x < \pi, u(x, \infty) = 0$ for $0 < x < \pi$.
7. Given Pauli matrices are $\sigma_x = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad \sigma_z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$. For the operator $A = \sigma_z + 2I$ explain how to compute A^{-1} numerically and why inverses matter in quantum operator equations.
8. For Hamiltonian matrix $H = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$ explain why finding eigen values of H gives the allowed energy of a quantum system.


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9. If a 2- qubit state is represented as matrix $M = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$ Explain how performing SVD on M helps to find whether the state is entangled.
10. A qubit gives outcomes 0 (prob. P) and 1 (prob. 1-P). Explain how to compute its mean and variance, relating variance to measurement uncertainty
11. The tunneling probability is $T = e^{-2KL}$. Describe how Monte Carlo sampling of random barrier widths L can estimate the average tunneling probability.
12. Fit $y = a(b^x)$ by the method of least squares to the data given below.

x	0	1	2	3	4	5	6	7
y	10	21	35	59	92	200	400	610

13. Determine the spring constant of a coupled oscillator by performing parallel and anti-parallel oscillations.
14. Determine how relaxation processes smear out the Rabi oscillations and affect the final population.
15. Calculate the probability of finding the system in the other bare state, $|2\rangle$, at a later time t. How does this probability oscillation frequency relate to the energy eigenvalues?

Course Outcomes–Program Outcomes–Program Specific Outcomes (CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	M	M	H	-	H	-	-	-	-	-	-	-	H	M	-
CO2	H	M	-	H	-	-	-	-	-	-	-	-	H	M	-
CO3	M	M	H	M	H	-	-	-	-	-	-	H	H	H	-
CO4	-	H	M	-	-	-	-	-	-	-	-	M	M	H	-
CO5	H	-	H	H	H	-	-	-	H	M	H	M	H	H	-

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23QTT04: Basics for Quantum Technologies

Credits – 2
L:T:P::2:0:0

Sessional Marks: 30
University Marks:70

Course Objectives

To expose the students to the following:

1. Understand basic optical and electronic circuit experiments.
2. Use RF instruments like oscilloscopes for signal analysis.
3. Analyze networks using Vector Network Analyzers.
4. Interface lab instruments with computers for data acquisition.
5. Run basic quantum algorithms on simulators and cloud platforms.

Course outcomes

After successful completion of course, the student should be able to

- CO1. Basic experimental techniques in optics
- CO2. Basic experimental techniques in characterizing resonators and RLC circuits
- CO3. Basic digital circuits
- CO4. Fundamental techniques in RF engineering
- CO5. Interfacing instruments with computers and carry out data acquisition

UNIT – I

Optics: Interferometry – wavelength measurements, intensity measurements, Diffraction – single slit, grating, Microscopy – magnification, aberration, Polarization optics – PBS, HWP, QWP

RLC circuits: Series and parallel RLC circuits – Verifying the quality factor formulae, Extracting intrinsic losses

Digital circuits: Adder, Multiplier, Encoder, Decoder, D flipflop, shift registers, How to use common Integrated Circuit chips

UNIT –II

Radio Frequency Technology: Using Oscilloscope - Ring-up and ring-down time measurements of RLC circuits, Measurements of different pulse-shapes generated by a function generator

UNIT – III

Using Vector Network Analyser: Transmission and reflection measurements of coaxial cable in open, short and matched termination, Voltage standing wave ratio measurement, Amplitude and Phase quadrature, In-phase and Out-of-phase quadrature plots and Quality factor measurement of RLC circuits, Characterising S-parameters, ABCD and Z matrices of common 2 port networks – coaxial cable, attenuator, low pass high pass bandpass filters etc., Characterising 3 port networks – directional couplers, circulators, isolators, Noise from a resistor at different temperatures

UNIT – IV

Interfacing instruments with a computer: Data acquisition: Signal demodulation – heterodyne vs Homodyne, Mixing of signals, Sampling, digitisation using ADCs – under-sampling and aliasing, oversampling and noise, Averaging and interpolation techniques

UNIT – V

Quantum Simulators: Running quantum protocols in a quantum simulator, implementing simple quantum


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Minor/Honor Degree for UG Degree course in Quantum Technologies

algorithms on cloud-based quantum computers, Running simple algorithms on cloud-based quantum processors

Course References:

1. Optics, Eugene Hecht, A. R. Ganesan, 5th edition, Pearson (2019)
2. Art of Electronics, Paul Horowitz and Winfield Hill, 3rd edition, Cambridge University Press (2015)
3. Digital Design, Morris Mano, Michael D. Cilletti, 6th edition, Pearson Education (2018)
4. Microwave Engineering, David Pozar, 4th edition, Wiley (2013)
5. Discrete-time signal processing, Alan V. Oppenheim and Ronald W. Shaffer, 4th edition, Pearson (2009)
6. Optical quantum information and quantum communication, A. Pathak and A. Banerjee, SPIE Spotlight Series, SPIE Press (2016)

Course Outcomes–Program Outcomes–Program Specific Outcomes (CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	M	H	-	-	-	-	-	-	M	H	M	-
CO2	H	H	M	M	H	-	-	-	-	-	-	H	H	M	-
CO3	H	H	M	M	H	-	-	-	-	-	-	H	H	H	-
CO4	H	H	M	M	H	-	-	-	-	-	-	H	H	M	-
CO5	H	H	M	H	H	-	-	-	M	M	M	H	H	H	-


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Course Objectives

To expose the students to the following:

1. Understand basic optical and electronic circuit experiments.
2. Use RF instruments like oscilloscopes for signal analysis.
3. Analyze networks using Vector Network Analyzers.
4. Interface lab instruments with computers for data acquisition.
5. Run basic quantum algorithms on simulators and cloud platforms.

Course outcomes

After successful completion of course, the student should be able to

- CO1. Basic experimental techniques in optics
- CO2. Basic experimental techniques in characterizing resonators and RLC circuits
- CO3. Basic digital circuits
- CO4. Fundamental techniques in RF engineering
- CO5. Interfacing instruments with computers and carry out data acquisition

LIST OF EXPERIMENTS

Optics:

1. Determine the wavelength of given light using plane transmission grating.
2. Study the intensity distribution due to diffraction from single slit and determine the slit width (d).
3. Verify Malus law.
4. Produce circularly and plane polarized light using the Quarter Wave Plate (QWP).

RLC circuits:

5. Determine the resonance frequency and quality factor for Series RLC circuits.
6. Determine the resonance frequency and quality factor for Parallel RLC circuits.
7. Determine Extracting intrinsic losses in RLC circuits.

Digital circuits:

8. Design full adder circuit and verify its functional table.
9. Design Multiplier circuit and verify its functional table.
10. Verify the functional table for 3:8 Encoder
11. Verify the functional table for 8:3 Decoder
12. Verify the truth table of D flip flop.
13. Verify the operation of 4-bit Universal Shift Register for different Modes of operation.

Radio Frequency Technology:

14. Measure the Ring-up and ring-down time of RLC circuits using Oscilloscope.
15. Measure the different pulse-shapes generated by a function generator.

Using Vector Network Analyzer:

16. Measure the transmission and reflection measurements of coaxial cable in open, short and matched termination.
17. Measurement of Voltage standing wave ratio for coaxial cable.



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18. ABCD and Z matrices of common 2 port networks.
19. Characterizing S-parameters for 3 port networks – directional couplers, circulators, isolators.

Interfacing instruments with a computer:

20. Extract the signal from noise by using heterodyne vs Homodyne Detectors.
21. Verify the output of Mixing of signals in modulator.
22. Verification of sampling theorem.

Quantum Simulators:

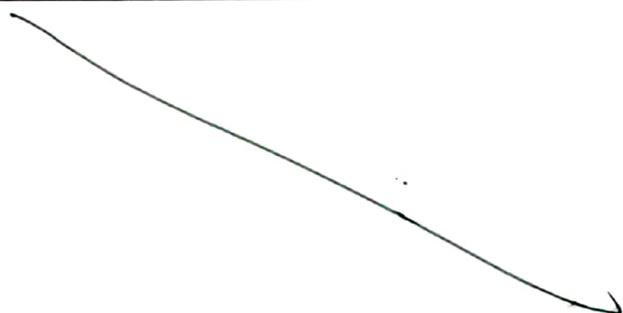
23. Write a program to create a quantum Qubit and measuring it using QISKIT
24. Write a program to apply an X-gate (NOT Gate) to a Qubit using QISKIT
25. Demonstrate the Deutsche-Jozsa algorithm and Groover’s algorithm using Qniverse quantum simulator

Course References:

1. Optics, Eugene Hecht, A. R. Ganesan, 5th edition, Pearson (2019).
2. Art of Electronics, Paul Horowitz and Winfield Hill, 3rd edition, Cambridge University Press (2015).
3. Digital Design, Morris Mano, Michael D. Cilletti, 6th edition, Pearson Education (2018)
4. Microwave Engineering, David Pozar, 4th edition, Wiley (2013)
5. Discrete-time signal processing, Alan V. Oppenheim and Ronald W. Shaffer, 4th edition, Pearson (2009).
6. Optical quantum information and quantum communication, A. Pathak and A. Banerjee, SPIE Spotlight Series, SPIE Press (2016).

Course Outcomes–Program Outcomes–Program Specific Outcomes (CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	M	H	-	-	-	-	-	-	M	H	M	-
CO2	H	H	M	M	H	-	-	-	-	-	-	H	H	M	-
CO3	H	H	M	M	H	-	-	-	-	-	-	H	H	H	-
CO4	H	H	M	M	H	-	-	-	-	-	-	H	H	M	-
CO5	H	H	M	H	H	-	-	-	M	M	M	H	H	H	-



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23QTT05: Introduction to Quantum Computation

(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Credits-3

Sessional Marks: 30

L:T:P::20:2
3:0:0

University Marks:70

Course Objectives :

1. Understand qubits, physical realizations, quantum gates, and quantum entanglement.
2. Review classical computation models and explore quantum logic gate universality.
3. Learn foundational quantum algorithms and their advantages over classical counterparts.
4. Understand Quantum Fourier Transform, Shor's algorithm, and advanced quantum algorithms.
5. Explore quantum error correction, NISQ devices, and the roadmap toward quantum advantage

Course outcomes:

Students of this course learn

1. To review the basic postulates of quantum mechanics
2. The theoretical basics of qubits and their physical realizations
3. To work with density operators and time evolution for mixed states
4. The basic ideas of quantum gates
5. The working of important quantum algorithms

UNIT – I

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

UNIT – II

Review of Turing machines and classical computational complexity: Time and space complexity (P, NP, PSPACE), Reversible computation, Universal quantum logic gates and circuits

UNIT – III

Quantum algorithms: Deutsch algorithm, Deutsch Josza algorithm, Bernstein - Vazirani algorithm, Simon's algorithm

Database search: Grover's algorithm

UNIT – IV

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

UNIT – V

Introduction to Error correction: Fault-tolerance, Simple error correcting codes, Survey of current status, NISQ era processors, Quantum advantage claims, Roadmap for future.

Course References:

1. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
2. Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
3. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, Florida, CRC Press, 2019

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CRC Press (2015)

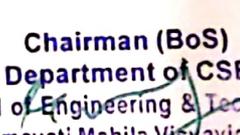
4. Quantum error correction and Fault tolerant computing, Frank Gaitan, 1st edition, CRC Press (2008)
5. Quantum computing explained, David McMahon, Wiley (2008)
6. Introduction to Quantum Computing: From a lay person to a programmer in 30 steps, Hui Yung Wong, 1st edition, Springer-Nature Switzerland AG (2022)

Course Outcomes–Program Outcomes–Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	M	M	-	-	-	-	-	-	M	H	M	-
CO2	H	H	-	M	H	-	-	-	-	-	-	M	H	H	-
CO3	H	H	-	M	M	-	-	-	-	-	-	M	H	H	-
CO4	H	H	M	M	H	-	-	-	-	-	-	H	H	H	-
CO5	H	H	M	H	H	-	-	-	-	-	-	H	H	H	-


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23QTT06: Introduction to Quantum Communication
(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Credits-3

L:T:P::3:0:0

Sessional Marks: 30

University Marks:70

Course Objectives :

- 1.Understand the fundamentals of polarization optics and optical detection techniques.
- 2.Learn basic digital communication theory and key quantum communication concepts like entanglement, quantum memories, and Bell's theorem.
- 3.Study quantum communication protocols including teleportation, dense coding, and quantum key distribution (QKD).
- 4.Explore the structure and functioning of quantum networks and the quantum internet.
- 5.Examine various hardware platforms used for implementing quantum communication systems

Course Outcomes:

Students of this course learn

1. The basics of EM theory
- 2.The basics of photodetection
- 3.The basics of information theory
- 4.The central ideas in quantum communications

UNIT – I

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

UNIT – II

Digital communication – Basics of information theory, Information entropy, Noiseless channel encoding, Noisy channel encoding. No cloning theorem, Quantum Memories, Quantum repeaters, Entanglement and Bell Theorems, Bell Measurements and Tests

UNIT – III

Quantum Teleportation protocol: Quantum Dense coding, Quantum Key Distribution protocols: BB84, E91, BBM92, B92, COW, DPS

UNIT – IV

Quantum Networks and Quantum Internet

UNIT – V

Survey of Hardware implementations: Free space communications, Satellite based communications, Fibre optics-based communications

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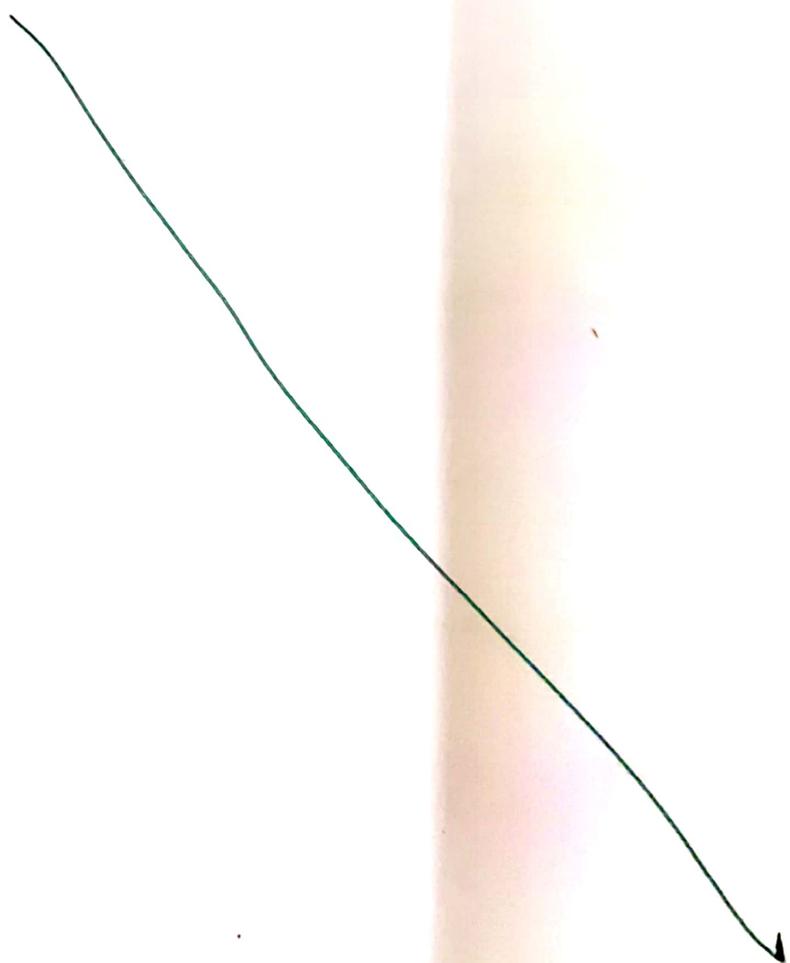


Course References:

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)

Course Outcomes – Program Outcomes – Program Specific Outcomes (CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	L	M	-	-	-	-	-	-	M	H	L	-
CO2	H	H	-	M	H	-	-	-	-	-	-	M	H	M	-
CO3	H	H	-	M	M	-	-	-	-	-	-	M	H	H	-
CO4	H	H	M	H	H	-	-	-	-	-	-	H	H	H	-



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23QTT07: Introduction to Quantum Sensing
(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Credits-3
L:T:P::3:0:0

Sessional Marks: 30
University Marks:70

Course Objectives :

- 1.Understand classical sensing techniques, types of noise, and sensitivity limits using statistical tools.
- 2.Learn the principles of quantum measurements and associated uncertainty and disturbance relations.
- 3.Explore quantum states of light and their representation using phase-space distributions.
- 4.Study quantum photodetection methods and quadrature measurements.
5. Analyze quantum sensing applications using photons, entanglement, atoms, and solid-state spins.

Course Outcomes:

Students of this course learn

- 1.The basics of classical sensing
- 2.Aspects of quantum measurement
- 3.Ways to quantify quantum sensing
- 4.About measurements of quantum states of light
- 5.About the applications of quantum sensing

UNIT-I

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

UNIT-II

Quantum measurements: projective/orthogonal measurements, Approximate/non-orthogonal measurements, Weak continuous measurements, Error-disturbance relations, Standard quantum limits, Quantum non-demolition measurements

UNIT-III

States of light: Fock states, Coherent states, Squeezed states, Tomography, Wigner quasi-probability distribution, P-distribution, Husimi Q function

UNIT - IV

Quantum photo detection: Square-law detectors, Intensity measurements and Photo-detection, Linear Detectors and Quadrature Measurements

UNIT - V

Quantum Cramer-Rao bounds: Single photon-based sensing applications, Entanglement based sensing applications, Atomic state-based sensing, solid-state spin-based sensing applications (gravimetry, magnetometry)

Course References:

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 .

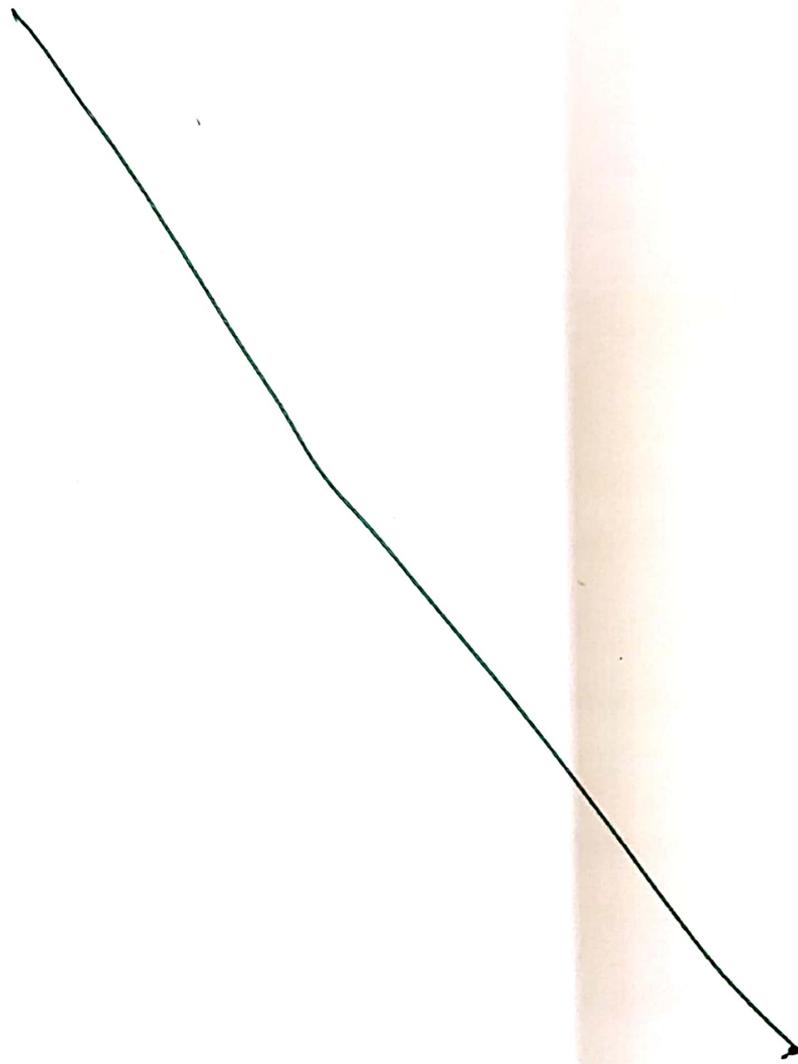
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Course Outcomes-Program Outcomes-Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	M	H	-	-	-	-	-	-	M	H	L	-
CO2	H	H	-	H	H	-	-	-	-	-	-	H	H	H	-
CO3	H	H	M	H	H	-	-	-	-	-	-	H	H	H	-
CO4	H	M	-	M	H	-	-	-	-	-	-	M	H	M	-
CO5	H	H	M	H	H	L	M	L	M	M	M	H	H	H	-



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23QTT08: Introduction to Quantum Materials

Credits-3 (Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

L:T:P::3:0:0

Sessional Marks: 30

University Marks:70

Course Objectives :

1. Understand band theory and semiconducting devices relevant to quantum technologies.
2. Learn fundamental concepts of magnetism and superconductivity, and their device applications.
3. Explore the properties and applications of 2D materials like graphene and TMDCs.
4. Study topological phases of matter and associated quantum phenomena.
5. Gain knowledge of various material synthesis and crystal growth techniques.

Course Outcomes:

Students of this course learn

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

UNIT – I

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

UNIT – II

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

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

UNIT – III

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

UNIT – IV

Topological Phases of matter: Basics of Topology, Geometric phases - Berry Phase, Aharonov Bohm effect, Topological phases of matter

UNIT – V

Survey of material growth techniques: Molecular beam epitaxy, Chemical vapor deposition, MOVPE, Pulsed laser deposition, etc., Crystal growth techniques

Course References:

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

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Course Outcomes-Program Outcomes-Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	M	-	M	H	-	-	-	-	-	-	-	-	-	-
CO2	H	H	-	M	H	-	-	-	-	-	-	M	H	L	-
CO3	H	H	-	M	H	-	-	-	-	-	-	H	H	H	-
CO4	H	H	-	M	H	-	-	-	-	-	-	H	H	H	-
CO5	H	M	M	M	H	L	M	L	M	M	M	M	H	M	-
CO6	H	H	M	H	H	-	-	-	-	-	-	M	H	M	-

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23QTT09: Engineering Foundations of Quantum Technologies
(optional / additional)

Credits-3
L:T:P::3:0:0

Sessional Marks: 30
University Marks:70

Course Objectives :

1. Understand analog electrical circuits, transmission lines, and analog communication techniques.
2. Learn digital communication theory, computer architecture basics, and computational complexity.
3. Explore abstract computation models like FSMs and Turing Machines and the language hierarchy.
4. Study different types of noise, noise characterization, and signal amplification principles.
5. Understand basic cryptography concepts and protocols, including post-quantum cryptographic methods.

Course Outcomes:

Students of this course learn

- 1.Relevant topics from Electrical Networks to design and analyse analog circuits
- 2.Relevant topics from RF and Microwave Engineering to design systems
- 3.Relevant topics in Theory of computation to benchmark algorithms
- 4.Relevant topics in analog and digital communications
- 5.Basics of cryptography

UNIT – I

Electrical Networks: Analog RLC circuits – resonances, impedances, quality factors, Transmission line basics: Telegrapher equations, wave impedance, impedance matching, transmission line resonators
Electrical Communications: Analog Communications: Quadrature amplitude modulation, Heterodyne and Homodyne demodulation

UNIT – II

Digital Communications: Information entropy, Noiseless channel encoding, Noisy channel encoding
Computer Science: Basics of computer architecture: Arithmetic Logic Unit, Memory
Complexity Theory: Time and Space complexity, P vs NP, NP-completeness

UNIT – III

Abstract models of computation: Finite State Machine, Turing Machines, Overview of Hierarchy of languages – Regular, Context-Free, Turing Decidable and Turing Recognizable

UNIT – IV

Noise and Signals: Characterizing Noise, Types of Noise: Shot Noise, Johnson-Nyquist Noise, Telegraphic noise or flicker or $1/f$ noise, Signal conditioning and noise mitigation, Amplification and Added Noise: Linear Amplifier theory, Signal-Noise Ratio, Added Noise, Noise Figure of amplification, Dynamic Range, Noise temperature, Quantum limits on noise in linear amplifiers

UNIT – V

Basics of cryptography: Basics of Number Theory, Random Number Generation, One-time pad, Private key, public key, symmetric and asymmetric cryptography protocols, RSA and DH, Post Quantum Cryptography (PQC)

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3. Microwave Engineering, David Pozar, 4th edition, Wiley (2013)
4. Information Theory, Robert B. Ash, Dover Publications (2003)
5. Introduction to the Theory of Computation, Michael Sipser, 3rd edition, Cengage India Pvt. Ltd. (2014)
6. Protecting Information – From Classical error correction to quantum cryptography, Susan Loepf and William K. Wootters, Cambridge University Press (2006)

Course Outcomes–Program Outcomes–Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	H	M	M	H	-	-	-	-	L	-	M	H	M	-
CO2	H	H	M	M	H	-	-	-	-	-	L	M	H	M	-
CO3	H	H	M	M	H	-	-	-	L	-	-	H	M	H	-
CO4	H	H	L	M	H	L	L	-	-	L	-	H	H	M	-
CO5	H	H	M	M	H	L	-	M	-	M	M	H	M	H	-

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23QTT10: Solid State Physics for Quantum Technologies
(optional / additional)

Credits-3
L:T:P::3:0:0

Sessional Marks: 30
University Marks:70

Course Objectives :

1. Understand crystal structures, symmetry, and basic diffraction principles in solids.
2. Learn about crystal bonding, metallic conduction, and electronic properties in solids.
3. Study band theory of solids using models like Kronig-Penney and tight-binding.
4. Explore vibrational properties of solids and fundamentals of magnetism.
5. Understand the theories and phenomena of superconductivity.

Course Outcomes:

Students of this course learn

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

UNIT – I

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

UNIT – II

Characterization of crystal structures – XRD etc., Bonding in solids: van der Waals and Repulsive interactions, Lennard Jones potential, Madelung constant
The Drude theory of metals: DC & AC electrical conductivity of a metal, Hall effect & magnetoresistance, Density of states, Fermi-Dirac distribution, Specific heat of degenerate electron gases, Free electron model

UNIT- III

Beyond the Free electron model: Kronig-Penney Model, Periodic potential – Bloch Theorem, Band theory, Tight binding model

UNIT- IV

Phonons in Solids: One dimensional monoatomic and diatomic chains, Normal modes and Phonons, Phonon spectrum, Long wavelength acoustic phonons and elastic constants, Vibrational Properties- normal modes, acoustic and optical phonons.
Magnetism: Dia-, Para-, and Ferromagnetism, Langevin's theory of paramagnetism, Weiss Molecular theory

UNIT – V

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

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Course References:

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

Course Outcomes–Program Outcomes–Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	H	L	M	M	-	-	-	-	L	-	M	H	L	-
CO2	H	H	M	M	H	-	-	-	-	L	L	H	H	H	-
CO3	H	H	M	M	M	-	-	-	-	L	-	H	M	M	-
CO4	H	M	M	M	M	-	-	-	-	L	-	M	M	H	-
CO5	H	M	M	M	H	-	-	-	-	L	M	H	M	H	-

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23QTT11: Quantum Optics
(optional / additional)

Credits-3
L:T:P::3:0:0

Sessional Marks: 30
University Marks:70

Course Objectives :

1. Understand quantization of the electromagnetic field and phenomena like photon bunching and interference.
2. Learn the theory of optical coherence and its role in interferometry and coherence measurements.
3. Study phase-space representations and recognize non-classical states of light using tools like the Wigner and P-functions.
4. Explore classical, semiclassical, and quantum models of light-matter interaction, including the Rabi and Jaynes-Cummings models.
5. Understand open quantum systems and master equations governing dissipative quantum dynamics.

Course Outcomes:

Students of this course learn

1. To quantise the electromagnetic field
2. The various experimental techniques in photonics
3. The various representations of states of light
4. Classical, semi-classical and fully quantum models of light-matter interaction
5. Modelling decoherence through Master equation

UNIT – 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

UNIT – II

Theory of Optical coherence, Young's double slit experiment and first order coherence, Coherence functions of arbitrary order, Normal ordering, symmetric ordering and anti-normal ordering of operators
Interferometry

UNIT – 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

UNIT – 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

UNIT – V

Open quantum systems, Fermi golden rule Born-Markov Lindblad Master Equation

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

Course Outcomes–Program Outcomes–Program Specific Outcomes(CO-PO-PSO) Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	H	H	M	M	M	-	-	-	-	L	-	H	H	H	-
CO2	H	H	M	H	H	-	-	-	M	M	M	H	H	M	-
CO3	H	M	M	M	M	-	-	-	-	L	-	H	M	H	-
CO4	H	H	M	H	M	-	-	-	-	L	-	H	H	H	-
CO5	H	H	M	H	M	-	-	-	-	L	-	H	M	H	-

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