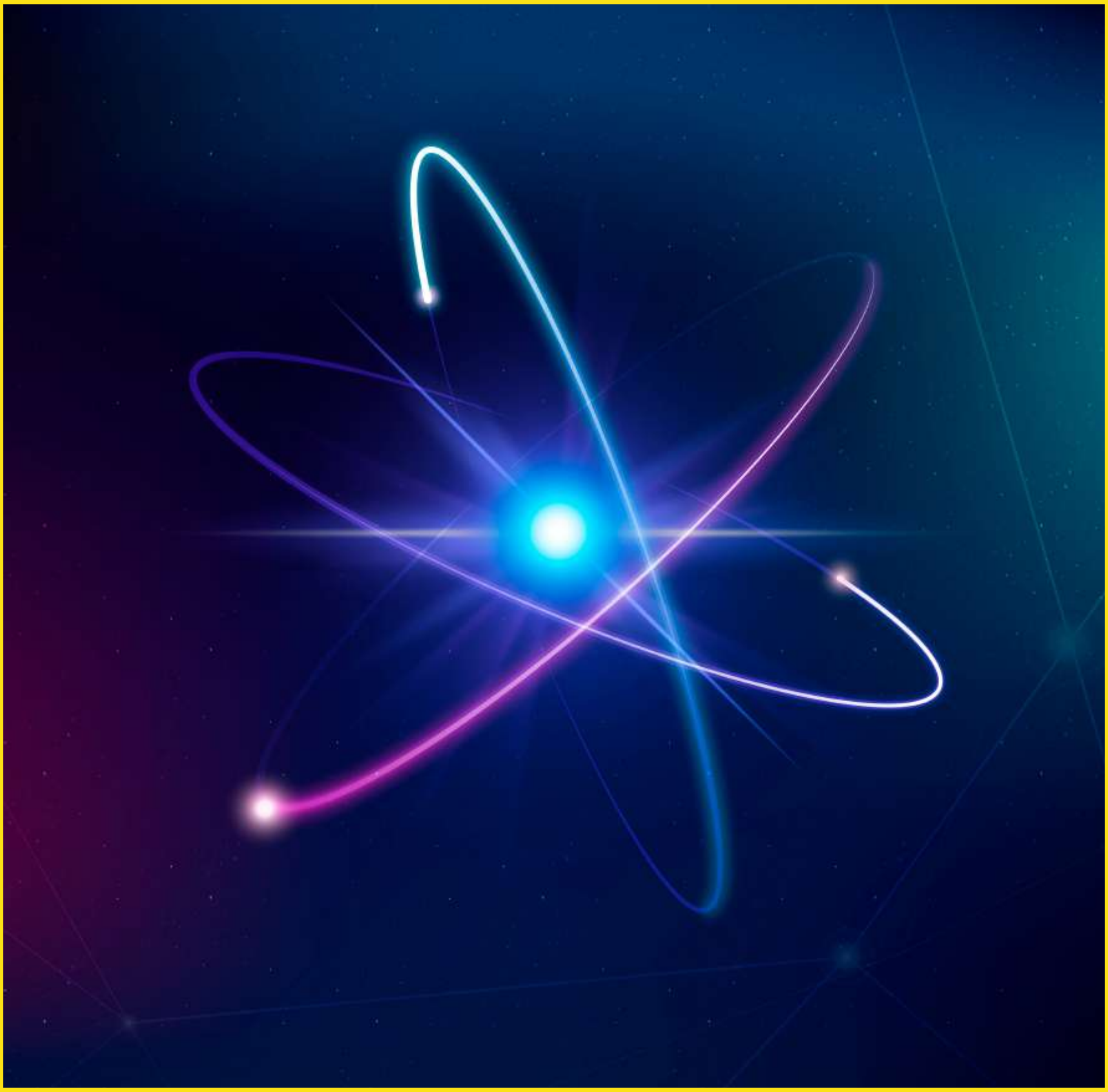
विज्ञान एवं प्रौद्योगिकी मंत्रालय
MINISTRY OF SCIENCE AND TECHNOLOGY
सत्यमेव जयते

Model Curriculum for M. Tech. Program in QUANTUM TECHNOLOGIES



अखिल भारतीय तकनीकी शिक्षा परिषद्
All India Council for Technical Education

Nelson Mandela Marg, Vasant Kunj, New Delhi, Delhi 110070 | www.aicte-india.org

MODEL CURRICULUM

for

M.TECH PROGRAM

in

QUANTUM TECHNOLOGIES

ALL INDIA COUNCIL FOR TECHNICAL EDUCATION

NELSON MANDELA MARG, VASANT KUNJ, NEW DELHI 110070

www.aicte-india.org

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सत्यमेव जयते

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MESSAGE

It gives me immense pride and pleasure to present the Model Curriculum for M.Tech in Quantum Technologies - a pioneering step towards building India's leadership in this cutting-edge domain.

The Government of India has launched the National Quantum Mission (NQM) with a vision to establish our nation as a global hub for quantum science, technologies, and applications. In alignment with this vision, the All India Council for Technical Education (AICTE), in close collaboration with the Department of Science and Technology (DST), has developed a comprehensive and forward-looking curriculum for postgraduate studies in Quantum Computing, Communication, Sensing, and Materials.

This curriculum has been carefully designed to strike the right balance between theoretical depth and practical exposure, enabling students to gain the expertise required for advanced research, innovation, and industry applications. It aims not only to nurture a highly skilled workforce but also to strengthen India's capabilities in a rapidly evolving global domain where investments and breakthroughs are accelerating at an unprecedented pace.

To complement classroom learning, specialised Teaching Laboratories in Quantum Technologies will soon be established across AICTE-approved institutions. These labs will provide hands-on training, interdisciplinary exposure, and innovation opportunities - fostering a vibrant ecosystem for capacity building, skill development, and entrepreneurship.

I am confident that this initiative will not only reinforce India's scientific and technological foundations but also inspire our youth to push the frontiers of knowledge and innovation in this transformative field.

On behalf of AICTE, I extend my sincere gratitude to DST and the distinguished experts whose contributions have shaped this curriculum. Together, we are laying a strong foundation for a future where India innovates, and the world celebrates our leadership in Quantum Technologies.

Prof. T.G. Sitharam

सत्यमेव जयते

प्रो. अभय करंदीकर
Prof. Abhay Karandikar

सचिव
भारत सरकार
विज्ञान एवं प्रौद्योगिकी मंत्रालय
विज्ञान एवं प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

27th August, 2025

MESSAGE

It is with immense pride that we announce the launch of the M. Tech Programme in Quantum Technologies, a collaborative initiative of the Department of Science & Technology (DST) and the All-India Council for Technical Education (AICTE) under the National Quantum Mission (NQM). This programme represents a major milestone in India's educational and technological landscape, aimed at preparing a new generation of specialists in one of the most transformative frontiers of science and innovation.

Quantum technologies hold the promise of revolutionizing diverse fields such as quantum computing, secure communication, precision sensing, advanced metrology, and novel materials. To realize this potential, the M.Tech. curriculum has been meticulously crafted by leading experts to integrate rigorous theoretical foundations with practical laboratory training, applied research, and exposure to real-world challenges. Graduates of this programme will be well-equipped to contribute as innovators, researchers, entrepreneurs, and technology leaders in shaping the future of this critical domain.

This initiative highlights our enduring commitment to nurturing highly skilled human resources, fostering a culture of innovation, and building a robust national ecosystem in quantum technologies.

I strongly encourage universities and technical institutions across the country to adopt this programme and help create a strong and sustainable talent pipeline that will accelerate India's journey towards becoming a global leader in quantum science and technology.

I also extend my sincere appreciation to all contributors, curriculum designers, and stakeholders whose dedication, expertise, and vision have made this programme a reality.

(Abhay Karandikar)

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Committee for Model Curriculum

S.No	Name	Designation
1.	Prof. Arindam Ghosh, IISc. Bangalore	Chairperson
2.	Ms. Anindita Banerjee, C-DAC, Pune	Member
3.	Prof. Rajendra Singh, IIT Delhi	Member
4.	Prof. Kasturi Saha, IIT Bombay	Member
5.	Dr. Swati Rawal, Scientist, DST	Member
6.	Sh. Sridhar CV, Head Quantum Initiatives, TCS	Member
7.	Sh. L Venkata Subramaniam, IBM Quantum, India	Member
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10.	Prof. Anirban Pathak, Jaypee Institute of Information Technology, Noida	Member
11.	Prof. Sunil Nair, IISER Pune	Member
12.	Prof. Anil Prabhakar, IIT Madras	Member
13.	Dr. D V Phani Kumar, DST	Member
14.	Sh Atul Tripathi , AI Expert	Member

Course Structure
of
M. Tech Program
on
Quantum Technologies

Preamble

Quantum Technology is an emerging new paradigm that promises to disrupt and revolutionize computing, communication and sensing in the coming decades. Keeping in mind the immense strategic potential, and possibilities for unforeseen breakthroughs in research, the global investment from Governments alone exceeds 40 B$. In the Indian context, the National Quantum Mission from the Government of India is a decisive step in accelerating the nation's research in this field. To fulfil the mandates of the mission, India needs to develop a highly skilled workforce through immediate initiatives in teaching and training. The training imparted to this workforce must enable them to reach global standards, and simultaneously address the multi-disciplinary needs of quantum technology development -- from core hardware and back-end engineering support to algorithms for cryptography and machine learning. To create a thriving quantum-trained ecosystem in India it is thus imperative to introduce a dedicated curriculum at the undergraduate level, as well as at the postgraduate level, along with programmes for faculty members and teachers involved in undergraduate and postgraduate education. While institutes of national importance have begun programs to this end, expanding such training to a larger pool of institutes across the country enables the nation to tap into the vast resource of students who can then participate in the mission to accelerate its progress towards its goals.

In this context we propose the course structure for a master of technology program (M. Tech) in Quantum Technologies at the graduate level. Here we consider Quantum Technologies to include all four verticals -- Quantum computation and simulation, Quantum communications and cryptography, Quantum sensing, Quantum materials and devices. We propose a curriculum spanning a minimum of 80 credits, spread over 4 semesters. We propose both theory and lab courses in this curriculum. The course structure is divided into core courses, specialization electives, open electives, and a project. We also encourage institutions and students to incorporate project-based learning approaches wherever possible to enhance the impact of the curriculum.

We have designed the curriculum keeping in mind the core requirements of a degree at the graduate level diversity in the institutions, as well as the different engineering disciplines. We believe that this minor program can be taken up by students of ALL engineering disciplines.

The students undertaking this course need to be familiar with undergraduate engineering mathematics, Maxwell's equations and electromagnetic theory at the level of the core undergraduate physics syllabus from AICTE model curriculum, physics at high school level (newton's laws, optics, thermodynamics), along with the basics of programming (simple arithmetic operations, basic sorting and search algorithms). These basic prerequisites are easily met by most students pursuing an undergraduate program under the AICTE model curriculum.

We believe that extensive training programs for teachers are necessary to enable them to do justice to the goals of the M. Tech program. Such sustained teacher training efforts will also enhance the quality of the training imparted to students over the years leading to long-term benefits and enable India to become a world leader in this field. We also believe that a text-book writing exercise should be carried out to cater to the needs of this graduate level program in quantum technologies.

Proposed structure of the program:

Minimum credits to fulfil – 80 Credits

1. L: T: P course amounts to at L lecture hours per week, T tutorial hours per week and P practical hours per week. The total credits for such a course are considered to be L+T+(P/2), with the understanding that 2 hours of practicals per week amount to 1 credit.
2. The first semester has only core courses, amounting to 22 credits.
3. We propose a 20 credit project, with 5 credits allocated to it in the 3rd semester, and 15 credits in the final semester.
4. The proposed curriculum has 39 credits of core courses, a minimum of 12 credits of specialisation electives and 9 credits of open electives.

Contents

Table of courses for M. Tech programme in Quantum Technologies

Course Code	Course Type	Title	Contact hours (Lecture: Tutorial: Practical)	Credits
First Semester				
QTM 01	Core	Mathematical Methods for Quantum Technologies	3:1:0	4
QTM 02	Core	Principles of quantum mechanics	3:1:0	4
QTM 03	Core	Overview of Quantum Technologies (Seminar)	1:1:0	2
QTM 04	Core	Classical and Quantum Information Theory	3:1:0	4
QTM 05	Core	Programming for Quantum Technologies	0:0:4	2
QTM 06	Core	Quantum Technologies lab 1	0:0:4	2
QTM 07	Core	Technical Communication	1:1:0	2
Second Semester				
QTM 08	Core	Introduction to Quantum Sensing	3:1:0	4
QTM 09	Core	Introduction to Quantum Materials	3:1:0	4
QTM 10	Core	Introduction to Quantum Computation	3:1:0	4
QTM 11	Core	Introduction to Quantum Communication	3:1:0	4
QTM 12	Core	Quantum Technologies lab 2	0:0:4	2
Spec Elec 1	Spec Elec		3:1:0	4
Third semester				
Spec Elec 2	Spec Elec		3:1:0	4
Spec Elec 3	Spec Elec		3:1:0	4
Open Elective 1	Open Elective		3:0:0	3
Open Elective 2	Open Elective		3:0:0	3
Open Elective 3	Open Elective		3:0:0	3
QTM 13	Core	Industry Seminar Course	1:0:0	1
QTM 14*	Core	Project	0:0:10	5
Fourth semester				
QTM 15*	Core	Project	0:0:30	15

***** – Project is considered under the lab for credits.

Prerequisites for all courses: Undergraduate Engineering Mathematics, Maxwell's equations and EM theory at the level of the core undergraduate physics syllabus from AICTE model curriculum.

Detailed Courses and Syllabus

Mathematical Methods for Quantum Technologies

QTM 01	**Mathematical Methods for Quantum Technologies**	**(3:1:0)**

This course is meant to give an overview of the mathematical methods used in quantum technologies.

Course Content and syllabus:

1. Brief review of Complex algebra
   i. complex numbers - real and imaginary parts, argand plane
   ii. polar representation
2. Linear Algebra, Matrix techniques
   i. Applications of linear algebra to quantum mechanics
3. Ordinary differential equations and initial value problems
   i. Applications of ODEs to harmonic oscillator, driven harmonic oscillator, damped harmonic oscillator
4. Partial differential equations and boundary value problems
   i. Applications of PDEs – wave equation, electromagnetic waves
5. Probability and Statistics
   a. Random Variables
   b. Probability distributions
   c. Gaussian Random variables – Law of large numbers, Central Limit Theorem
   d. Applications of Probability and Statistics to Physics
      i. Gibbs principle and computing average thermal energy and fluctuations
      ii. Noise characterisation

Course Outcomes:
Students of this course will learn -

1. Linear algebra and matrix methods to solve problems
2. Ordinary and Partial differential equations
3. Probability and Statistics
4. Applications of all the above in quantum technologies

Course References:

1. Engineering Mathematics, Erwin Kreyszig,
2. Mathematical Methods for Physicists , Arfken and Weber

*****

Principles of Quantum Mechanics

QTM 02	Principles of Quantum Mechanics	(3:1:0)

This course is meant for laying down the central theoretical aspects of quantum mechanics in a rigorous manner where students learn the techniques and develop a good intuition for quantum physics.

Course Content and syllabus:

1. Postulates of Quantum Mechanics
2. Dirac Bra-Ket notation
3. 1D potential problems
4. Approximation techniques (perturbation theory, variational techniques)
5. Angular momentum algebra and identical particles (Bosons and Fermions)
6. Density operator and mixed states, limitations of closed quantum systems and basic ideas of open quantum systems
7. Basic ideas of foundational issues (quantum foundations, entanglement, etc.)

Course Outcomes:

Students of this course will learn -

1. Basic postulates of quantum mechanics
2. Solving problems of 1 D potentials in quantum mechanics
3. Approximation techniques and variational techniques
4. Density operator formalism for mixed states
5. Basic ideas of open quantum systems
6. Basic ideas of quantum foundations like entanglement

Course References:

1. Introduction to Quantum Mechanics, Griffiths D. J., 3rd Edition, Cambridge University Press (2024)
2. Principles of Quantum Mechanics, Shankar, R., 2nd edition, Springer (2014)
3. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
4. Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
5. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)

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Overview of Quantum Technologies

QTM 03	Overview of Quantum Technologies	(1:1:0)

This course is meant to familiarize students, through weekly seminars, with current developments in all four verticals of quantum technologies. The seminar should cover the real life industry use cases so that students are industry-ready.

Course Content and syllabus:

1. Weekly seminars by experts
2. Seminars on select topics by students encouraging self-study and literature review

Course outcomes:

Students of this course will learn -

1. Developments in quantum technologies
2. Will learn to do self-study on select topics and present their understanding
3. Write a report on the talks they listened to during the course

Course References:

Not Applicable

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Classical and Quantum Information Theory

QTM 04	Classical and Quantum Information Theory	(3:1:0)

Course Content and syllabus:

1. Basics of classical information theory – Shannon information entropy
2. noiseless channel encoding
3. noisy channel encoding
4. von Neumann entropy
5. Entanglement and its measures
6. quantum channel capacity
7. Heuristic ideas of classical networks
8. Quantum Networks and Quantum Repeaters
9. Quantum Communication Protocols

Course outcomes:

Students of this course will learn -

1. Basics of classical information theory
2. Basics of quantum information theory
3. Basics of quantum communication protocols

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, CRC Press (2015)

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Programming for Quantum Technologies

QTM 05	Programming for Quantum Technologies	(0:0:4)

Course Content and syllabus:

1. Basics of programming
   i. Data structures
2. Basics of algorithms
   i. sorting
   ii. searching
3. Basics of Python
4. Basics of Julia
5. Basics of Qasm
6. Using toolboxes for quantum technologies in these languages
7. Simulations of simple closed and open quantum systems in packages like QuTiP
8. Using Frameworks such as Cirq, Pennylane, Qiskit

Course outcomes:

Students of this course will learn -

1. The basics of programming
2. Basics of Python, Julia, Qasm
3. To use tool boxes for quantum technologies in these languages
4. To use frameworks like Cirq, Pennylane, Qiskit

Course References:

1. CUDA-Q https://nvidia.github.io/cuda-quantum/latest/index.html
2. Qiskit Textbook https://github.com/Qiskit/textbook 2023
3. Official python tutorial: https://docs.python.org/3/tutorial/index.html
4. Think Python: How to Think Like a Computer Scientist, 2nd edition, Allen B. Downey (O'Reilly, 2015)

*****

Quantum Technology Lab 1

QTM 06	Quantum Technology Lab 1	(0:0:4)

Course Content and syllabus:

1. Digital Electronics – logic gates
    i. Combinational circuits
        a. Half and Full Adder
        b. Decoder and Encoder
    ii. Sequential circuits
        a. Flipflops and Shift Registers
2. Analog electronics
    i. RLC filters
        a. Frequency domain modeling of RLC circuits
        b. Low pass and high pass characteristics
        c. Quality Factor
    ii. Diode Circuits
        a. Rectification and Envelope Detection
    iii. Op Amp circuits
        a. Inverting and Non-inverting amplifiers
        b. Adder circuits
3. Simple experiments that show quantum nature
    i. Franck-Hertz
    ii. Photoelectric effect
    iii. Balmer lines
    iv. Compton scattering
    v. Band gap of semiconductors
4. Basics of Optical Bench
5. Linear Optical elements
    i. Beam splitters
    ii. Polarizers, Half-wave plates and Full-wave plates
    iii. Diffraction gratings
6. Michelson interferometer on an optical bench
7. Mach-Zender interferometer (optional)

Course Outcomes:

Students of this course will learn -

1. Basics of digital electronics and logic gates
2. Basics of analog circuits
3. Basics of optical experiments - polarisation, interference

Course References:

1. ELECTRONIC DEVICES AND CIRCUIT THEORY,Boylestad / Nashelsk, Pearson Publication
2. Optics Experiments and Demonstrations for Student Laboratories: Principles, methods and applications (IOP Series in Emerging Technologies in Optics and Photonics), Professor Stephen G Lipson, Part of: IOP Series in Emerging Technologies in Optics and Photonics
3. Fundamentals of Photonics, Bahaa E. A. Saleh, Malvin Carl Teich, 2 Volume Set, 3rd Edition, , ISBN: 978-1-119-50687-4

*****

Technical Communication

QTM 07	Technical Communication	(1:1:0)

Course Content and syllabus:

- Student seminars on select scientific topics
- Written term papers on scientific topics
- Literature Survey and Research paper analysis
- Popular science communication

Course Outcomes:

Students of this course will learn -

1. The basics of technical writing
2. The basics of technical oral communication
3. Research paper analysis
4. Popular science communication

Course References:

1. NA

*****

Introduction to Quantum Sensing

QTM 08	Introduction to Quantum Sensing	(3:1:0)

Course Content and syllabus:

1. Classical sensing
   i. photo detection
2. Classical Noise
   i. Johnson Noise, Telegraph noise, flicker or 1/f noise
3. Sensitivity of classical measurements
   i. Classical Fisher information
   ii. Cramer - Rao bounds (information theory basics may be required here).
4. Quantum measurements
   i. projective/orthogonal measurements
   ii. Approximate/non-orthogonal measurements
   iii. Weak continuous measurements
   iv. Error-disturbance relations
   v. Standard quantum limits
   vi. Quantum non-demolition measurements
5. States of light
   i. fock states
   ii. Coherent states
   iii. Squeezed states
   iv. Tomography
   v. Wigner quasi-probability distribution
   vi. P-distribution
   vii. Husimi Q function
6. Quantum photo detection
   i. Square-law detectors, Intensity measurements and Photo-detection
   ii. Linear Detectors and Quadrature Measurements
7. Quantum Cramer-Rao bounds
8. Single photon-based sensing applications
9. Entanglement based sensing applications
10. Atomic state-based sensing, solid-state spin-based sensing applications (gravimetry, magnetometry)

Course Outcomes:

Students of this course will learn -

1. The basic ideas of classical sensing and classical noise
2. The basics of quantum measurement
3. The basics of quantum sensing
4. Quantum Cramer-Rao bounds
5. Single and Entangled photon-based sensing applications

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 (2023)

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Introduction to Quantum Materials

QTM 09	Introduction to Quantum Materials	(3:1:0)

Course Content and syllabus:

1. Band theory basics
   i. Metals, Semiconductors and Insulators
   ii. Band structure of solids
   iii. Survey of semiconducting devices for quantum technologies (electronic, quantum optical devices and principle of operation)
2. Correlated systems
3. Magnetism
   i. Para, ferro magnetism basics
   ii. Magnetic measurements, hall effect, magnetoresistance
   iii. Faraday and Kerr effects
4. Superconductivity
   i. BCS theory
   ii. Ginzburg Landau
   iii. Josephson Effect – AC and DC Josephson effects
   iv. Survey of superconducting devices for quantum technologies
5. 2D materials
   i. Graphene and its properties – single and few layers
   ii. Transition Metal Dichalcogenides – Electronic and Optical Properties
6. Topological Phases of matter
   i. Basics of Topology
   ii. Geometric phases - Berry Phase
   iii. Aharonov Bohm effect
   iv. Topological phases of matter
7. Survey of material growth techniques
   i. Molecular beam epitaxy
   ii. Chemical vapor deposition, MOVPE
   iii. Pulsed laser deposition, etc.
   iv. Crystal growth techniques

Course Outcomes:

In this course, students will learn

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

Course References:

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

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Introduction to Quantum Computation

QTM 10	Introduction to Quantum Computation	(3:1:0)

Course Content and syllabus:

1. Qubits versus classical bits
   i. Spin-half systems and photon polarizations
   ii. Trapped atoms and ions
   iii. Artificial atoms using circuits
   iv. Semiconducting quantum dots
   v. Single and Two qubit gates – Solovay - Kitaev Theorem
2. Quantum correlations
   i. Entanglement and Bell’s theorems
3. Review of Turing machines and classical computational complexity
   i. Time and space complexity (P, NP, PSPACE)
4. Reversible computation
5. Universal quantum logic gates and circuits
6. Quantum algorithms
   i. Deutsch algorithm
   ii. Deutsch Josza algorithm
   iii. Bernstein - Vazirani algorithm
   iv. Simon’s algorithm
7. Database search
   i. Grover’s algorithm
8. Quantum Fourier Transform and prime factorization
   i. Shor’s Algorithm.
9. Quantum complexity classes – Q, EQP, BQP, BPP, QMA
10. Additional Topics in Quantum Algorithms
    i. Variational Quantum Eigensolver (VQE)
    ii. HHL
    iii. QAOA
11. Introduction to Error correction
    i. Fault-tolerance

ii. Simple error correcting codes

12. Survey of current status

i. NISQ era processors

ii. Quantum advantage claims

iii. Roadmap for future

Course outcomes:

Students of this course will learn -

1. The theoretical basics of qubits and their physical realisations
2. To work with density operators and time evolution for mixed states
3. The basic ideas of quantum gates
4. The working of important quantum algorithms
5. The basics of quantum error correction

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, 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)

*****

Introduction to Quantum Communication

QTM 11	Introduction to Quantum Communication	(3:1:0)

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

Course Content and syllabus:

1. Basics of Polarization optics
   i. Quarter and half-wave plates
   ii. Polarizing beam splitters
2. Basics of linear and square-law detectors
   i. Quadrature amplitude modulation
   ii. Heterodyne and Homodyne demodulation and linear detectors
   iii. Intensity measurements and square law detectors
   iv. Photomultipliers, Avalanche Photo diodes
3. Digital communication – information theory (basics)
   i. Information entropy
   ii. Noiseless channel encoding
   iii. Noisy channel encoding
4. No cloning theorem
5. Quantum Memories
6. Quantum repeaters
7. Entanglement and Bell Theorems
8. Bell Measurements and Tests
9. Quantum Teleportation protocol
10. Quantum Dense coding
11. Quantum Key Distribution protocols
    i. BB84
    ii. E91
    iii. BBM92.
    iv. B92
    v. COW
    vi. DPS
12. Quantum Networks and Quantum Internet

13. Survey of Hardware implementations
    i. Free space communications
    ii. Satellite based communications
    iii. Fibre optics-based communications

Course Outcomes:

Students of this course will 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

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).

*****

Quantum Technology Lab 2

QTM 12	Quantum Technology Lab 2	(0:0:4)

Course Content and Syllabus:

1. RF Electronics
   i. IQ Modulation and Demodulation
2. Noise spectral measurements
3. Correlation and coherence measurements
   i. FPGA electronics
   ii. coherent source
   iii. thermal noise source.
4. Optics
   i. Mach Zender interferometer
   ii. Coherence measurements of light sources
   iii. Single photon detection
5. Quantum Experiments (free space)
   i. Heralded Photon and entangled photon generation, measurement and validation experiments
   ii. HoM tests, quantum state tomography
   iii. Grangier exp
   iv. Bell test
   v. quantum optical gates realization
   vi. Single photon interferometry (this may include MZI/sagnac)
   vii. Biphoton experiment
   viii. Applications: Quantum random number generator from entangled source
   ix. BB84
6. Simulations of Open quantum systems
7. Running quantum algorithms on classical simulators, as well as on available cloud quantum processors.

Course Outcomes:

Students of this course will learn -

1. To do advanced experiments in RF and microwave regime
2. To work with FPGA electronics
3. Advanced experiments in optics
4. Advanced experiments with single and entangled photons
5. Simulate open quantum systems
6. Running quantum algorithms on classical simulators, and available quantum processors (optional, subject to access)

Course References:A Guide to Experiments in Quantum Optics, Hans-A. Bachor and Timothy C. Ralph, Second Edition – Wiley-VCH

Industry Seminar

QTM 13	**Industry Seminar**	**(1:0:0)**

Course Content and syllabus:

- Seminars by relevant Industry personnel

Course outcomes:

Students of this course will learn -

1. Work going on in industry in quantum technology and allied areas
2. Networking for jobs etc.

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Project 1

QTM 14	**Project 1**	**(0:0:10)**

Course Content and Syllabus:

- Project

Course Outcomes:

- Project

*****

Project 2

QTM 15	**Project 2**	**(0:0:30)**

Course Content and Syllabus:

- Project

Course Outcomes:

- Project

*****

DETAILED SYLLABUS OF SUGGESTED SPECIALISATION ELECTIVES

Optimization Problems (Specialisation Elective)

Optimization Problems (Specialisation Elective)	(3:1:0)

Course Content and Syllabus:

1. Modeling for LPP and Integer Programs
2. Linear Programming (Graphical Method)
3. Simplex, Dual Simplex, Revised Simplex Method
4. Big M & Two-Phase Method
5. Branch and Bound Method
6. Branch and Cut Method
7. KKT condition (Karush–Kuhn–Tucker)
8. Gradient Descent algorithm
9. Newton Raphson algorithm
10. Dual Ascent and Dual Decomposition method
11. Augmented lagrangian method
12. Bayesian Optimisation
13. Applications (Portfolio optimisation, TSP, Capacity planning)

Course Outcomes:

1. Formulate and solve **Linear/Integer/Non-linear Programming problems**.
2. Apply **advanced optimization methods** (Simplex, Branch & Bound, Gradient Descent, Bayesian Optimization).
3. Demonstrate optimization applications in **Portfolio, TSP, and Capacity Planning**.

Course References:

1. Ability to model real-world decision-making problems mathematically.
2. Skills to analyze problems and implement computational algorithms.
3. Problem-solving competence for engineering, business, and research domains.

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Classical and Quantum-assisted machine learning

Classical and Quantum-assisted machine learning	(3:1:0)

Course Content and syllabus:

1. Basic statistical approaches
   i. regression, classification
2. Machine learning approaches
   i. Deep learning
   ii. Reinforcement learning
3. Learning models
   i. Supervised and Unsupervised
   ii. Support vector machines
   iii. Back propagation
   iv. Feedback
   v. Predictive models
   vi. Generative AI (with specific attention to content generation)
   vii. Agentic AI
4. Neural network approaches
   i. RNN, CNN, GNN, KNN
5. Quantum counterparts of the classical models
   i. Quantum support vector machine
   ii. Quantum back propagation
   iii. Quantum RNN
   iv. Quantum CNN
6. Use cases of quantum assisted machine learning
   i. Image analysis
   ii. Image recognition
   iii. Facial recognition
   iv. Voice recognition
   v. Computer vision
   vi. Character recognition
   vii. Weather forecasting
   viii. Satellite imaging.

Course outcomes:

Students of this course will learn -

1. Models of Machine Learning
2. Neural Networks
3. Quantum Assisted Machine Learning
4. Applications of Machine Learning

Course references:

1. Bishop, Christopher M., 2006, *Pattern Recognition and Machine Learning,* New York :Springer.
2. Maria Schuld and Francesco Petruccione, 2018. *Supervised Learning with Quantum Computers (1st. ed.).* Springer Publishing Company

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Advanced Quantum Algorithms

Advanced Quantum Algorithms	(3:1:0)

Course Content and syllabus:

1. Review of basic quantum algorithms
   i. Deutsch Josza
   ii. Berstein-Vazirani
   iii. Grover Search
   iv. Shor's algorithm
2. Variational Quantum Algorithms
   i. VQE
   ii. QAOA
   iii. Use cases
3. Quantum walks
4. Basic statistical approaches
   i. regression, classification
5. Machine learning approaches
   i. Deep learning
   ii. Reinforcement learning
6. Neural network approaches
   i. RNN, CNN, GNN, KNN
7. Quantum counterparts of the classical models
   i. Quantum support vector machine
   ii. Quantum back propagation
   iii. Quantum RNN
   iv. Quantum CNN)
8. Use cases of quantum assisted machine learning
   i. Image analysis
   ii. Image recognition
   iii. Facial recognition
   iv. Voice recognition
   v. Computer vision

vi. Character recognition
vii. Weather forecasting
viii. Satellite imaging.

Course outcomes:

Students of this course will learn -

1. Variational Quantum Algorithms
2. Quantum Assisted Machine Learning
3. Applications of VQA and Quantum Assisted Machine Learning

Course references:

1. Nielsen, M.A. & Chuang, I.L., 2011. *Quantum Computation and Quantum Information: 10th Anniversary Edition*, Cambridge University Press.
2. Lipton, R.J. and Regan, K.W., 2021. Introduction to quantum algorithms via linear algebra. MIT Press.
3. Mermin, N.D., 2007. Quantum computer science: an introduction. Cambridge University Press.
4. Wittek, P., 2014. Quantum machine learning: what quantum computing means to data mining. Academic Press.

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Post Quantum Cryptography

Post Quantum Cryptography	(3:1:0)

Course Content and syllabus:

1. Review of ideas of Classical Cryptography
   i. RSA
2. Vulnerabilities of the traditional classical cryptography
   i. Shor's Algorithm
3. Hardware requirements for quantum cryptography
   i. Need for PQC.
4. Different mathematical approaches to PQC
   i. Lattice-Based Cryptography
   ii. Code-Based Cryptography
   iii. Hash-Based Cryptography
   iv. Isogeny-Based Cryptography
   v. Multivariate Cryptography
5. NIST recommendations
6. Security analysis of PQC schemes and possible attacks on PQC schemes.
7. Specific use cases of PQC schemes- key distribution, virtual meeting platforms, authentication, etc.

Course Outcomes:

Students of this course will learn -

1. Review classical cryptographic ideas
2. Vulnerabilities of classical cryptography - especially RSA
3. Need for PQC
4. Mathematical approaches to PQC

Course References:

1. Post-Quantum Cryptography: Bernstein D.J., Buchmann J. and Dahmen E. (Eds.); Springer, 2010
2. Douglas R. Stinson and Maura B. Paterson, 2018, *Cryptography: Theory and Practice*, 4th edition, CRC Press
3. William Stallings, 2012, *Cryptography and Network Security: Principle and Practice*, 5th edition, Pearson

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Solid State Physics

Solid State Physics	(3:1:0)

Course Content and syllabus:

1. Introduction to the solid phase of matter
   i. Typical properties of solids
   ii. Microscopic structure of solids – crystalline, amorphous.
2. Crystal structure
   i. Bravais lattices
   ii. Unit cells
   iii. Wigner-seitz unit cell
3. Real and k-spaces
   i. Brillouin zones.
4. Phonons and vibrational modes of solids
   i. 1d lattice and phonon dispersion
   ii. Lattice with bases
   iii. Optical and acoustic phonon modes.
5. Electrons in solids
   i. Drude model
   ii. Bloch theorem
   iii. Density of States in different dimensions
   iv. Band Theory of solids
   v. Conductors, insulators and semiconductors.

Course Outcomes:

Students of this course will 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 electrons in solids
5. Band Structure

Course References:

1. Introduction to Solid State Physics, Charles Kittel, Wiley India Edition (2019)
2. Solid State Physics, Ashcroft and Mermin,
3. Condensed Matter Physics, M P Marder, 2nd Edition, John Wiley and Sons (2010)

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Quantum Optics

Quantum Optics	(3:1:0)

Course Content and syllabus:

1. Quantization of the electromagnetic field
    i. Number states, coherent states, squeezed states
    ii. Hanbury-Brown and Twiss experiments – Photon bunching, Photon anti bunching
    iii. Hong-Ou-Mandel interference
2. Theory of Optical coherence
    i. Young's double slit experiment and first order coherence
    ii. Coherence functions of arbitrary order
    iii. Normal ordering, symmetric ordering and ani-normal ordering of operators
    iv. Interferometry
3. Phase-space representations of states of light
    i. Wigner distribution
    ii. P-function and the notion of non-classicality with some examples of nonclassical states like squeezed states and their applications
    iii. Husimi Q function
4. Light-matter interaction
    i. Classical model of light-matter interaction
    ii. Semi-classical model of light-matter interaction-
    iii. Quantum light-matter interaction
    iv. Rabi Model
    v. Jayne's-cummings model
5. Open quantum systems
    i. Fermi golden rule
    ii. Born-Markov Lindblad Master Equation

Course Outcomes:

Students of this course will 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

Course References:

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)
5. Agarwal, Girish S. *Quantum optics*. Cambridge University Press, 2012

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Optical Communication

Optical Communication	(3:1:0)

Course Content and syllabus:

1. Overview of optical communications
   i. free space communications
   ii. fibre based communications - O, C and L bands, ITU grid
2. Optical transmitter components
   i. Lasers and LEDs
   ii. optical modulation - direct and indirect
3. Digital modulation formats:
   i. ASK, PSK, and QAM, simulation models,
   ii. Optical implementation, simulation models
4. Optical receivers
   i. Photodetectors and its performance characteristics,
   ii. noise in photodetection, noise equivalent power
   iii. transimpedance amplifier
5. Lasers
   i. rate equations
   ii. linewidth and coherence of a laser
6. Electromagnetic theory,
   i. Wave equations
   ii. Reflection and transmission of waves
   iii. Divergence of a beam in an isotropic medium
7. Optical fibers
   i. single and multi-mode fibers,
   ii. attenuation and dispersion
8. Multiplexing
   i. Polarization, wavelength and time multiplexing
   ii. WDM components - multiplexer/demultiplexer, add/drop, directional coupler

Course Outcomes:

Students of this course will learn to

1. do a power budget analysis for an fibre optic link
2. design a free space optical experiment
3. model the different modulation formats used in optical communication

Course References:

1. Optical Fibre Communications, Gerd Keiser, Wiley, 5th ed, 2019
2. Optical Fibre Communications, J. M. Senior, Prentice Hall, 3rd ed, 2009
3. https://onlinecourses.nptel.ac.in/noc21_ee42/preview
4. https://onlinecourses.nptel.ac.in/noc20_ee79/preview

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