भारतीय प्रौद्योगिकी संस्थान जोधपुर
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Curriculum M. Tech. in Quantum Technologies

Cat.	*Course Number, Course Title*		*L-T-P*	*Credits*		*Cat.*	*Course Number, Course Title*		*L-T-P*	*Credits*
I Semester						**II Semester**				
C	QCL7XX0	QUANTUM Computation	3-0-0	3		C	QCLXX0	Quantum Inspired Optimization	2-0-2	3
C	QCL7XX0	Introduction to Quantum Information	2-0-2	3		E	QCL7XX0	*Elective*	3-0-0	3
C	QCL7XX0	Quantum Cryptography and Coding	3-0-0	3		E	QCL7XX0	*Elective*	3-0-0	3
E	QCL7XX0	Elective	3-0-0	3		E	QCL7XX0	*Elective*	3-0-0	3
NG1	HSN7XX0	Non-Graded I	1-0-0	S/X		NG2	HSN7XX0	*Non-Graded II*	1-0-0	S/X
			Total	**12**					*Total*	**12**
III Semester						**IV Semester**				
T	MET8XXo	Thesis		16		T	MET8XX0	Thesis		16
			Total	**16**					*Total*	**16**

Electives

S. No.	Course Number	*Course Title*		
1		Open Quantum Systems	3-0-0	3
2		Device Independent Quantum Technologies	3-0-0	3
3		Quantum Error Correction	3-0-0	3
4		Seminal features of Quantum Information Processing	3-0-0	3
5		Advanced Quantum Cryptography	3-0-0	3
6		Classical Quantum Information Theory	3-0-0	3
7		Continuous Variable Quantum Information	3-0-0	3

S. No.	*Category*	*Course Category Title*	*Total Courses*	*Total Credits*
1	C	*COMPULSORY*	4	12
2	E	*ELECTIVES*	4	12
3	NG	*Non-Graded*	2	0
3	T	Thesis	**2 (16+16)**	32
		Total		**56**

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Title	*Quantum Computing*	Number	QCL7XX0
Department		L-T-P (C)	3-0-0 (3)
Offered for		Type	
Prerequisite			

Objectives
The instructor will:
1. Provide fundamentals of quantum computation.
2. Impart the knowledge of modelling algorithms for various computational problems.

Learning Outcomes
The students are expected to:
1. Use the concepts taught in class to various aspects of quantum computation.
2. Understand and appreciate the technological evolution of quantum computation.

Contents
Mathematical Preliminaries [8 lectures]: Overview of linear algebra, Postulates of quantum mechanics, concept of bits and qubits, quantum states and density operators, Bloch sphere, no-cloning theorem.

Quantum-Circuit Model [12 Lectures]: Reversible versus irreversible gates, the joy of superposition and entanglement, Clauser-Horne-Shimony-Holt inequality as a nonlocal game, single and multi-qubit operations, Measurements, Implementing multi-qubit gates, Universal quantum gates.
Quantum Algorithms [15 Lectures]: Quantum Coin—Deutsch's Algorithm, Deutsch-Jozsa and Bernstein-Vazirani Algorithms, Simon's Algorithm, Phase estimation and quantum Fourier transform, Eigenvalue estimation, The order-finding problem, Shor's algorithm, Grover's search algorithm

Physical Implementation [4 Lectures]: Requirements- Preparation of initial states, Performance and limitations of unitary operations, Measurements, fidelity, Technological candidates for quantum computing.

Text Books

1. Nielsen, M. A. and Chuang, I. L., *Quantum Computation and Quantum Information*, 10th edition, Cambridge University Press (2000).
2. P. Kaye, R. Laflamme and M. Mosca, An Introduction to Quantum Computing, Oxford University Press.

References

1. C. Bernhardt, Quantum Computing for Everyone, MIT Press.
2. Quantum Computer Science: An Introduction” by means of N. David Mermin

Online Materials:

1. T. G. Wong, Introduction to Classical and Quantum Computing, www.thomaswong.net/introduction-to-classical-and-quantum-computing-1e4p.pdf
2. J. Watrous, Quantum Computing lecture Notes, https://johnwatrous.com/wp-content/uploads/2023/08/QC-notes.pdf
3. S. Aaronson, Introduction to Quantum Information Science Lecture Notes, https://www.scottaaronson.com/qclec.pdf
4. IBM Quantum Learning, https://learning.quantum.ibm.com/
5. Practice Quantum Computing, https://brilliant.org/courses/quantum-computing/?courseSlug=quantum-computing

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Title	*Introduction to Quantum Information*	Number	QCL7XX0
Department		L-T-P (C)	2-0-2 (3)
Offered for		Type	
Prerequisite			

Objective
The instructor will:
1. Provide fundamentals of quantum information.
2. Impart the knowledge of modelling efficient quantum information protocols.
3. Impart the knowledge of implementing some information processing protocols in practice.

Learning Outcomes
The students are expected to:
1. Use the concepts taught in class to various aspects of quantum information.
2. Understand and appreciate the technological evolution at theoretical and experimental fronts in quantum information.

Contents (Theory) [26 lectures]
Classical information theory: The concept of information, Shannon's information theory, Shannon entropy and data compression, Mutual information, Noisy channel coding. [6 Lectures]
Foundations of Quantum Information Theory: Quantum states and information, von Neumann entropy, Distinguishing quantum states, Schumacher compression, Holevo bound, Quantum channel coding. [8 Lectures]
And
Quantum Entanglement Theory: Quantum states, Separable and entangled states, separability criterion, measures of two-qubit and multiqubit entanglement, EPR paradox, Bell inequalities, Measures of quantum correlations [7 Lectures]

Applications: Quantum teleportation and superdense coding, entanglement swapping, random number generator. [5 Lectures]

Contents (Lab) [13 lectures]
List of Experiments (in open-source quantum platforms)
1. Introduction to open-source quantum platforms.
2. Visualizing Bloch vectors.
3. Understanding superposition.
4. Generation of multiqubit entangled states.
5. Implementation of entangling measurement.
6. Implementation of quantum teleportation.
7. Implementation of quantum superdense coding.
8. Implementation of BB84 cryptography.
9. Implementation of entanglement swapping.
10. Implementation of random number generator.

Text Books
1. Nielsen, M. A. and Chuang, I. L., Quantum Computation and Quantum Information, 10th edition, Cambridge University Press (2000).
2. Vedral, Vlatko (2006). Introduction to Quantum Information Science. Oxford, England: Oxford University Press.

Reference Books/papers
1. Mark M. Wilde, Quantum Information Theory, Cambridge University Press (2013)
2. Robert Loredo, Learn Quantum Computing with Python and IBM Quantum Experience, Packt Publishing (2020).
3. Hassi Norlen, Quantum computing in practice with Qiskit and IBM Quantum Experience, Packt Publishing (2020).

Online Materials:
1. IBM Quantum Learning, https://learning.quantum.ibm.com/
2. Practice Quantum Computing, https://brilliant.org/courses/quantum-computing/?courseSlug=quantum-computing

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Title	*Quantum Cryptography and Coding*	Number	QCL7XX0
Department	IDRP-QIC	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech./Ph.D.	Type	Elective
Prerequisite			

Objectives
The Instructor will:
1. Introduce the students to the fascinating field of cryptography and coding, with specific emphasis on the quantum aspects of it.
2. Highlight a number of facets of these theories having some parallel with the more familiar classical world.

Learning Outcomes
The students are expected to have the ability to:
1.Understand the fundamental principles of quantum cryptography and coding.
2. Become familiar with the modern aspects of the theory, including its experimental implementation.

Contents
Cryptography [10 Lectures]: Various aspects of modern cryptography; number theoretic concepts
Classical Coding Theory [10 Lectures]: Concepts of entropy, mutual information and related aspects; Shannon's coding theorem.
Basic concepts of Quantum Mechanics [5 Lectures]: From the perspective of information and cryptography: Hilbert space, states, operators: Hermitian and Unitary, simple measurements.
Some basic no-go theorems [2 Lectures]: With implications to cryptography.

Some basic applications pertinent to quantum cryptography [21 Lectures]: Entanglement, teleportation, dense coding, Quantum Key Distribution protocols: BB84, B92, Ekert protocol, Goldenberg-Vaidman, counterfactual quantum cryptography; protocols of quantum dialogue; Quantum secret sharing protocol; Quantum cheating and cryptography; Protecting information and QKA (quantum key agreement); Shor's factoring algorithm and modern cryptography; Experimental progress in quantum cryptography.
Quantum Coding[4 Lectures]: Quantum aspects of Shannon coding theorem. (4 Lectures)

Textbook:
1. Nielsen Michael, A. and Chuang Isaac , I., (2010), Quantum Computation and Quantum Information, Cambridge University Press, 2010.

Reference Books
1. Benenti, G., Casati, G., and Strini, G., (2004) Principles of Quantum Computation and Information, World Scientific Press, 2004
2. Bouwmeester, D., Ekert, A. and Zeilinger, A., (2000) The Physics of Quantum Information, 2nd edition, Springer, 2000

Self-Learning Material:
1. Shor, P., Quantum Computation,MIT Open Course, 18.435J Fall 2003, Link https://ocw.mit.edu/courses/mathematics/18-435j-quantum-computation-fall-2003/

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Title	*Quantum Inspired Optimization*	Number	MAL7xxxx
Department	Mathematics	L-T-P [C]	2–0–2 [3]
Offered for	MSc, M.Tech and Ph. D. Students	Type	Elective
Prerequisite	Any nonlinear optimization course and basic concepts of quantum introduction.		

Objectives:
1. Introduce quantum computing in optimization.
2. Formulation and solution of different optimization problems in quantum way.

Learning Outcomes:
1. Learn to solve different optimization problems using quantum annealers and digital quantum computer
2. Learn about more general optimization problems and about the Variational Quantum Eigen-solver

Contents:

Introduction of optimization: General optimization problem, local/global solution, integer programming, binary knapsack programming and applications(2 lecture]

Quadratic unconstrained binary optimization problems: Max cut problem and Ising model, Formulating the problem in quantum way, Moving from Ising to QUBO and back, Combinatorial optimization problems with QUBO model, Application in Knapsack prblems, Graph colouring etc. [5 lectures]

Adiabatic Quantum computing and quantum annealing: Adiabatic quantum computing, Quantum annealing, Constrained quadratic models in Ocean, Running constrained problem on quantum annealing [5 lectures]

Quantum approximate optimization algorithm: From adiabatic to QAOA,Using QAOA with Qiskit, Using QAOA with PennyLane, [3 lectures]

Grover adaptive search: Grover's algorithm, Quantum oracles for combinatorial optimization, Using GAS with Qiskit [3 lectures]

Quantum computing for Pseudo-Boolean Optimization: Basic transformations,Hadamard transform, σx transform,k-local Hamiltonian Problems,Graph structures and optimization problems [4 lectures]

Variational Quantum Eigensolver: Hamiltonians, observables, and their expectation values, Introduction of Variational Quantum Eigensolver, Using VQE with Qiskit, Using VQE and PennyLane [6 lectures]

Text Books:
1. Elias F. Combarro, Samuel Gonzalez-Castillo: A Practical Guide to Quantum Machine Learning and Quantum Optimization, Pact Publishing Ltd., Birmingham, 2023.
2. W. Cruz-Santos, G. Morales-Luna: Approximability of Optimization Problems through Adiabatic Quantum Computation, Morgan & Claypool Publishers, California, USA

Online study material:
Advances for Quantum-Inspired Optimization by INFORMS https://www.youtube.com/watch?v=qdrXL8HL3cQ

Title	*Open Quantum Systems*	Number	PHL 7480
Department	IDRP-QIC & Physics	L-T-P [C]	3–0–0 [3]
Offered for	Ph.D. and M.Sc. Programs	Type	ELECTIVE
Prerequisite	Knowledge of basic Quantum and Statistical Mechanics		

Objectives

The Instructor will:

1. Help in understanding the basic ideas of open quantum systems.
2. Help in grasping the basic models of dissipative quantum statistical mechanics.

Learning Outcomes

The students are expected to have the ability to:

1. Grasp the concepts of open quantum systems in various regimes.
2. Make contact of theoretical developments with experimental advances.

Contents

Introduction to quantum statistical mechanics [6 Lectures]: Density matrices; BCH Theorem; harmonic oscillator.
*Introduction to path integrals [7 Lectures]:*Partition function as a path integral; density matrix evolution as a path integral.
*Master Equations [8 Lectures]:*Liouville equation; Langevin equation; Fokker-Planck equation; Boltzmann equation; quantum dynamical semigroups and Lindblad equations; projection operator techniques.
*Dissipative Harmonic Oscillator[6 Lectures]:*Lindblad approach; quantum Brownian motion.
*Dissipative Two-State System[4 Lectures]:*Spin-Boson Model.
Quantum Thermodynamics and Heat Engines [4 Lectures]: Interface of quantum mechanics with thermodynamics; impact of quantum mechanics on heat engines.
*Interface with Quantum Information [7 Lectures]:*Role of open systems in quantum information; geometric phase; quantum cryptography.

Textbooks

1. Banerjee, S, (2018), *Open Quantum Systems: Dynamics of Nonclassical Evolution,* Springer, 2018
2. Breuer, H., -P., (2007), *The Theory of Open Quantum Systems,* Oxford University Press, 2007

Reference Book

1. Weiss, U., (2012), *Quantum Dissipative Systems*, World Scientific, 2012.

Online Course Material

1. Fraas, M., *Theory of Open Quantum Systems*, ITP Lecture Archive.

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Title	*Device Independent Quantum Technologies*	Number	QCL7XX0
Department	IDRP QCL	L-T-P (C)	3-0-0 (3)
Offered for	M.Tech., M.Tech-Ph.D. Dual Degree	Type	Program Elective
Prerequisite			

Objective
The Instructor will:

1. Impart the foundational mathematical framework for designing device-independent quantum technologies.
2. Discuss the state-of-the-art device independent technologies that leverage Bell nonlocality.

Learning Outcomes
The students are expected to have the ability to:

1. Understand how the fundamental laws of nature (here Bell's theorem) empower cutting-edge quantum technologies.
2. Be able to apply Bell's theorem to design device independent quantum technologies.

Contents
Introduction:
Recap of linear algebra, Postulates of quantum mechanics, EPR paradox [4L]

Review of Prerequisites for Device Independent (DI) Technologies:
Bell Nonlocality: Quantum formalism for qubit, Qubit deterministic model (Bell model), Bell's theorem and its implication, Quantum violation of Bell inequality - Refutation of Local Hidden Variable Theory, Nonlocality of PR correlation and its comparison with quantum nonlocality, Applications of Bell nonlocality: Device Independent Technology – motivation and definition. [8L]

Device Independent (DI) Technologies:
Certification of Entanglement: Entanglement witness, DI entanglement witness. [5L]
Certification of Randomness: Importance of randomness, Pseudo-random numbers, DI randomness certification. [6L]
Witnessing System Dimension: CGLMP inequality, Hardy's nonlocality paradox, DI certification of system dimension. [6L]
Self-testing of quantum states and measurements. [4L]
Cryptography: BBM92 protocol and its device dependency, Device independent secret key generation by PR correlation and possibility of extending it to quantum regime, DI Quantum Key Distribution. [7L]
Other Real-world Applications of Bell Nonlocality:
Quantum advantage in solving Bayesian game theoretic problems. [2L]

Text Books

1. Nielsen, M. A. and Chuang, I. L., *Quantum Computation and Quantum Information*, 10th edition, Cambridge University Press (2000).
2. Asher Peres, *Quantum Theory: Concepts and Methods (Fundamental Theories of Physics)*, Springer Science & Business Media (1995)
3. Jean-Daniel Bancal, *On the Device-Independent Approach to Quantum Physics: Advances in Quantum Nonlocality and Multipartite Entanglement Detection*, Springer International Publishing (2013)

Reference Books/papers

1. Bell nonlocality; Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner; Rev. Mod. Phys. 86, 419 (2014).
2. N. David Mermin, Hidden variables and the two theorems of John Bell; Rev. Mod. Phys. 65, 803 (1993).
3. Valerio Scarani, The device-independent outlook on quantum physics (lecture notes on the power of Bell's theorem), Acta Physica Slovaca 62, 347 (2012); arXiv:1303.3081

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Title	*Quantum Error Correction*	Number	QCL7XX0
Department	IDRP QCL	L-T-P (C)	3-0-0 (3)
Offered for	M.Tech., M.Tech-Ph.D. Dual Degree	Type	Program Elective
Prerequisite	-		

Objective
The instructor will:
1. Explore the fundamentals of classical and quantum error correcting codes.
2. Explain importance of learning classical error correcting codes in order to design effective quantum error correcting codes.
3. Discuss the state-of-the-art in classical and quantum error correction.

Learning Outcomes
The students are expected to have the ability to:
1. Appreciate the importance of error correction for the development of practical quantum computers and other quantum information technologies.
2. Explain the fundamental concepts of classical and quantum error correction.
3. Develop new type(s) of quantum error correcting method(s).

Contents:
Classical Error Correction: Basic idea of a classical channel, noisy classical channel, binary symmetric channel, why error correction is required, classical error correcting codes. [6L]
Quantum Operations and Noise: Quantum operation formalisms, Examples of quantum noise and quantum operations. [3L]
Quantum Error Correction: The need of quantum error correction, Bit-flip and phase flip codes, Shor's code. Theory of quantum error correction: discretization of errors, quantum Hamming bound, Quantum Gilbert-Varshamov bound, Singleton bound, Construction of quantum codes, classical linear codes, CSS codes, Stabilizer codes, the stabiliser formalism, Gottesman–Knill theorem, construction of stabiliser codes [20L]
Fault-tolerant quantum computation: Fault tolerant design, syndrome extraction, syndrome verification, measurement, examples, limitations and drawbacks. [10L]

Text Books
1. Nielsen, M. A. and Chuang, I. L., Quantum Computation and Quantum Information, 10th edition, Cambridge University Press (2000).
2. Frank Gaitan, Quantum error correction and fault tolerant quantum computing, CRC Press Inc (2008).

References
1. P. Kaye, R. Laflamme and M. Mosca, An Introduction to Quantum Computing, Oxford University Press.
2. D. A. Laider, and T. A. Burn, Quantum error correction, Cambridge University Press (2013).

Online Materials
1. Quantum Error Correction, Daniel Gottesman, https://www2.perimeterinstitute.ca/personal/dgottesman/CO639-2004/index.html
2. Quantum Error Correction, John Preskill, http://theory.caltech.edu/~preskill/ph229/notes/chap7.pdf

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Title	*Seminal features of Quantum Information Processing*	Number	QCL7XX0
Department	IDRP-QIC	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. , Ph.D.	Type	
Prerequisite	None		

Ojectives

The aim of this course is

1. To let students understand and appreciate evolution of the research area through seminal articles
2. To translate the fundamental and advanced topics towards research problems and solutions

Learning Outcomes

The students will be able to

1. Understand research problems, develop analytical thinking to formulate, solve and present a research problem in precise manner

Contents

Entanglement, Separability and Non-Locality [16 Lectures]: Foundations of quantum entanglement, Introductory and seminal contributions related to bi-partite and multiqubit entanglement, measures of entanglement, classification and quantification of nonlocal correlations, entanglement versus separability versus nonlocality, discord and geometrical discord, Multi-qubit nonlocality and open problems

Quantum communication Protocols [16 Lectures]: Role of entanglement as a resource for communicating information, limitation, multiqubit controlled communicationprotocols, splitting of information, open destination teleportation, quantum cryptography and post quantum cryptography, Bell-CHSH inequalities and quantum games, singlet fraction and efficiencies of quantum information processing protocols, Dealing with noise and its adverse effects, Experimental implementations

Model Problems, Analysis and Solutions [10 Lectures]: Students will be assigned model problems associates with entanglement, nonlocality and quantum communication, interactive discussion to increase analytical thinking and problem solving skills, a model manuscript preparation and submission

Text Books

1. Nielsen, M. A. and Chuang, I. L., (2010), Quantum Computation and Quantum Information, 10th Anniversary addition, Cambridge University Press

Reference Books/Articles

1. Bouwmeester, D., Ekert, A. and Zeilinger, A., (2000), The Physics of Quantum Information, Reprint edition, Springer Berlin Heidelberg
2. Einstein, A., Podolsky, B., and Rosen, N., Phys. Rev.47, 777 (1935)
3. Bennett, C. H., Brassard, G., Crepeau, C., Jozsa, R., Peres, A., and Wootters, W. K., Phys. Rev. Lett. 70, 1895 (1993)
4. Bennett, C. H., Bernstein, H. J., Popescu, S., and Schumacher, S., Phys. Rev. A53, 2046 (1996)
5. Peres, A., Phys. Rev. Lett. 77, 1413 (1996)
6. Horodecki, M., Horodecki, P., and Horodecki, R., Phys. Lett. A223, 1 (1996)
7. Bouwmeester D, Mattle K, Pan J. W., Weinfurter H., Zeilinger A., and Zukowski M., Nature390, 575 (1997)
8. Hilleri, M., Buzek, V., and Berthiaume, A., Phys. Rev. A 55, 1829 (1999)
9. Luo, S., Phys. Rev. A 77, 042303 (2008)
10. Kim, Y. S., Lee, J. C., Kwon, O., and Kim, Y. H., Nature Physics 8, 117 (2011)

Online Course Material:

1. Goswami, D., Quantum Computing, NPTEL course material, Department of Chemistry, IIT Kanpur, Link: https://www.youtube.com/watch?v=xnmpWfQKPSE&list=PLq-Gm0yRYwTj7Fs6jyzYa83HErSrpXgPQ

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Title	*Advanced Quantum Cryptography*	Number	MAL7xxx
Department	Mathematics	L-T-P [C]	3–0–0 [3]
Offered for	M.Sc., M. Tech., and Ph.D.	Type	Elective
Prerequisite	Linear algebra, complex analysis, probability, and foundations of cryptography		

Objectives

1. Introduce the basic concepts of classical cryptography and its limitations.
2. Explain the principles of quantum mechanics necessary for understanding quantum cryptography.
3. Learn how to use quantum effects, such as quantum entanglement and uncertainty, to implement cryptographic tasks with levels of security that are impossible to achieve classically.
4. Discuss the current research and future trends in quantum cryptography.

Learning outcomes

The students are expected to learn:

1. Fundamental toolbox for understanding, designing and analyzing quantum protocols,
2. quantum key distribution protocols,
3. how untrusted quantum devices can be tested,
4. modern quantum cryptography – beyond quantum key distribution.

Contents

1. What are quantum bits - qubits? Combining qubits using the tensor product, Measuring qubits, Performing operations on qubits, Bloch Sphere representation, Density matrices, Encrypting (quantum) bits: the classical and quantum pad, Combining density matrices using the tensor product, Classical-quantum states, Generalized measurements, The partial trace. [8 lectures]

2. What is quantum entanglement? Purification and Uhlman's theorem, The Schmidt Decomposition, Sharing a classical secret using entangled quantum states, Verifying entanglement using a Bell test, Monogamy of entanglement What it means to be ignorant: ideal case, Trace distance and its use in security definitions, The (min)-entropy including the smooth min-entropy, Uncertainty principles: simple version BB84, Extended UR principles: tripartite version. [8 lectures]

3. Privacy amplification, Randomness extractors, Randomness extraction using hashing, The measurement, Introduction to key distribution, Key distribution with a limited Eve and perfect Bob, Key distribution with noise on the channel. [6 lectures]

4. Quantum key distribution: definitions and concepts, BB84 states and Six states, BB84 Protocol, Purifying protocols using entanglement, Security from a guessing game, Authentication, Device- independent quantum cryptography, Testing devices using a Bell experiment, Security of device- independent quantum key distribution against collective attacks, Security against general attacks,Secure Function Evaluation, Oblivious transfer - the universal gate of cryptography, Bit commitment, Impossibility of bit commitment, Coin flipping. [12 lectures]

5. Evading impossibility, The noisy storage model, Bit commitment in the noisy-storage model, Security from quantum uncertainty, A universal primitive: weak string erasure, Position verification, Quantum computing in the cloud. [8 lectures]

Textbooks

1. Nielsen, M. A and Chuang, I. I., Quantum Computation and Quantum Information, Cambridge University Press 2000.
2. Jaeger, G., Quantum Information, Springer 2007.

Reference Books

1. Noson S. Yanofsky, and Mirco A. Mannucci, Quantum Computing for Computer Scientists, Cambridge University Press 2008.
2. avid J. Griffiths, Introduction to Quantum Mechanics, Cambridge University Press 2018.

Online Course Material

1. Caltech DelftX QuCryptox, Quantum Cryptography https://www.edx.org/course/quantum-cryptography

2. Shweta Agrawal, Quantum Algorithms and Cryptography, https://youtube.com/playlist?list=PLyqSpQzTE6M8Pp2Z8kOAVyoSbw1UOPWQY

Title	*Classical Quantum Information Theory*	Number	QCL7XX0
Department	IDRP (QC)	L-T-P [C]	3–0–0 [3]
Offered for	MTech	Type	SE
Prerequisite			

Objectives

1. To understand the interface between information theory and quantum mechanics
2. To get familiar with acquisition, storage, transmission and processing of information

Learning Outcomes

The students are expected to:
1. Appreciate the notion of information as a physical resource and its entropic characterization
2. Understand and analyze reliable transmission of accessible and coherent information over noisy channels

Contents

The notion of information as a physical resource, classical information, quantifying information, data compression and source coding, entropy, noisy channels and channel capacities, optimal coding and coding theorems, error corrections, Maxwell's demon and Landauer's principle [18 Lectures]

Quantum information and von-Neumann entropy, distance measures and fidelity, entropy and separability, Helstrom's discrimination- classical versus quantum information, quantum data compression, conditional and quantum mutual information, relative entropy and its interpretation, equalities and inequalities of entropy, subadditivity, Holevo bound and channel capacities, Quantum data compression and theorems, examples of quantum channels, coherent communication with noisy resources, classical information over quantum channels, entanglement-assisted quantum communication, entropy and thermodynamics, applications [24 Lectures]

Textbooks

1. Nielsen, M. A. and Chuang, I. L., (2000) *Quantum Computation and Quantum Information*, 10th edition, Cambridge University Press.
2. Vedral, V., (2006) *Introduction to Quantum Information Science,* 1st edition, Oxford University Press

Reference Books

1. Bellac, M. L., (2006) *A Short Introduction to Quantum Information and Quantum Computation*, 1st edition, Cambridge University Press.
2. Bouwmeester, D., Ekert, A. and Zeilinger, A., (2000) *The Physics of Quantum Information*, 2nd edition, Springer.

Self Learning Material

Goswami, D., *Quantum Computing*, *Mathematics for Chemistry,* NPTEL Course Material, Department of Chemistry, Indian Institute of Technology Kanpur https://onlinecourses.nptel.ac.in/noc18_cy07/preview

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Title	*Continuous Variable Quantum Information*	Number	QCL7XX0
Department		L-T-P (C)	3-0-0 (3)
Offered for		Type	
Prerequisite			

Objective
The instructor will:
1. Explore the fundamentals of continuous variable quantum mechanics.
2. Explain the importance of learning quantum information theory in a continuous variable framework.
3. Discuss the state-of-the-art in continuous variable quantum information theory.

Learning Outcomes
The students are expected to have the ability to:
1. Appreciate the importance of continuous variable quantum theory for the development of quantum technologies.
2. Explain the fundamental concepts of continuous variable quantum information.

Contents:
Quantized electromagnetic field and coherent state representation: Quantization of the electromagnetic field, State space formalism – Fock space, quadratures, coherent state, phase space representation, Gaussian states, non-classical states. [13L]

Continuous variable entanglement: Bipartite entanglement, separability criteria for Gaussian states, separability of multi-mode Gaussian states, entanglement distillation, entanglement measures, quantum nonlocality with continuous variable. [12L]

Quantum communication with continuous variables: Quantum teleportation, superdense coding, quantum key distribution, classical communication through quantum channels. [10L]

Quantum computation with continuous variables: Universal quantum computation, extension of Gottesman-Knill theorem. [4L]

Text Books
1. Alessio Serafini, Quantum Continuous Variables: A Primer of Theoretical Methods, CRC Press (2023)
2. G. S. Agarwal, Quantum Optics, Cambridge University Press (2012)

References
1. M. O. Scully, M. S. Zubairy, Quantum Optics, Cambridge University Press (1997)
2. C. Gerry, P. Knight, Introductory Quantum Optics, Cambridge University Press (1997)

Online Materials
1. S. L. Braunstein, P. van Loock, Quantum information with continuous variables, Rev. Mod. Phys. 77, 513 (2005)