PES UNIVERSITY

Ph.D. / MTech by Research course work syllabus

Physics

List of courses

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1	UE21PH841A	Renewable Energy & Energy Storage System
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5	UE23PH844A	Quantum Mechanics and Quantum Logic Circuits

UE21PH841A: Renewable Energy & Energy Storage System

This Course is intended to provide students an overview on energy storage schemes/devices with major focus on electrochemical storages including ionic batteries, fuel cells and super-capacitors. The course will cover operating principles and the physics behind

Course Objectives:

The course is designed to give the students

- An understanding of the principles of various kinds of renewable energy sources
- An insight of operational mechanisms of various energy storage systems.

Course Outcomes:

After the successful completion of this course, the student will be able to:

- Analyze the characteristics of energy from various sources and need for storage
- Classify various types of energy storage and various devices used for the purpose
- Identify various real time applications.

Course Outline

Unit 1: Silicon – Solar cells: Conventional Photovoltaic cells, characteristics and performance. Si nanostructure-Based Solar Cells, Si-Nanodot Solar Callas: Preparation of SI-NDs with Controllable Size, Optical and Electrical characteristics of SI-NDs in Dielectric Matrices, Stand-Alone Si Nanowire- Based Solar Cells: Optical and Electrical characteristics of Stand-Alone Si-NWs Arrays, Si Thin Film Solar Cells Textured with Si Nanostructures: Optical and Electrical characteristics

Unit 2: Piezoelectric Materials and Fuel Cells: Energy harvesting based on PZT nanofibers: Introduction, PZT nanofiber synthesis, Piezoelectric voltage constant of a single PZT nanofiber, Fabrication Process for nanogenerator, working principle, power generation mechanism, mathematical model, characterization of nanogenerator. Introduction of proton Exchange Membrane Fuel Cell (PEMFC) – characteristics and performance, Role of nanosized electrocatalysts for PEMFC, one, two and There -dimensional nano-electrocatalysts and metal oxide as the promotional component of electrocatalysts.

Unit 3: Electromagnetic Energy Storage: Energy Storage in Capacitors: Energy in a Parallel Plate Capacitor, Electrochemical Charge Storage Mechanisms, Electrostatic Energy Storage in the Electrical Double-Layer in the vicinity of an electrolyte/electrode interface, Comparative magnitudes of Energy Storage, Importance of the Quality of the Stored Energy.

Energy Storage in Magnetic Systems: Energy in a Material in a Magnetic Field, Energy Storage in Superconducting Magnetic Systems

Unit 4: Electrochemical Energy Storage systems: Primary Batteries: Introduction, Zinc-Carbon and Alkaline-Manganese Dioxide Batteries, zinc-air battery, Silver Oxide Battery. Secondary Batteries: Introduction, Lead-Acid Batteries, Nickel-Cadmium Battery, Nickel-Metal Hydride Battery, Lithium-Ion Battery, Lithium-Sulphur and Lithium -Air Batteries. Flow Batteries: Vanadium Redox Battery and Zinc-Bromine Battery. Supercapacitors: Introduction, Energy Storage in Supercapacitors, Fabrication of Supercapacitors, Main Types and structures of Supercapacitors, Electrochemical double-layer capacitor, Pseudo capacitor, Hybrid Capacitors, Fabrication of Single Supercapacitors Cell, Electrode Fabrication, Electrolyte, Separator, Cell Design

Unit 5: Energy Storage for Medium to Large-Scale Applications: Storage of Solar and wind-Generated Energy, Hybrid Lead-Acid Batteries for Large Scale Storage, Batteries with open Framework Crystal Structure Electrodes, Batteries with Prussian Blue Electrodes, Batteries with Liquid Electrodes, Sodium/Sulphur Batteries, All-Liquid Batteries, Storage of Energy for Vehicle Propulsion.

Reference Books:

1. Energy Efficiency and Renewable Energy Through Nanotechnology, Ling Zang Editor, Springer-Verlag Landon Limited 2011.
2. Electrochemical Energy Advanced Materials and Technologies, Edited by Pei Kang Shen Chao-yang Wang, San ping Jiang, Xueliang Sun and Jiuiun Zhang, CRC Press Taylor & Francis Group, 2016.
3. Energy Storage Fundamentals, Materials and Applications, Robert A. Huggins, Second Edition, Springer Cham Heidelberg NEW York Dordrecht London, 2016.

UE23PH841A: Battery Technology- Testing, Evaluation andApplications

This course covers the most recent advances in the, fabrication, testing, characterization, properties and applications of battery with an emphasis on recent technological breakthroughs in the field.

Course Objectives:

1. To have an updated knowledge of battery evaluation and design process.

2. To understand the various electrical and structural techniques to explore new material forbattery application

Course Outcomes:

After the successful completion of this course, the student will be able to:

1. Appreciate the need of electrical and structural techniques to understand the materialsbetter.

2. Understand various design and manufacturing process involved in battery making.

3. Know the performance evaluation process of batteries and its application.

Course Outline

Unit I: Electrochemical Analysis: Open-Circuit Voltage, Linear Sweep Voltammetry, Cyclic Voltammetry, Constant Current (Galvanostatic) Method, Cut-off Voltage Control, Constant Capacity Cut off Control, Constant Voltage (Potentiostatic) Method, Constant Voltage Charging, Potential Stepping Test AC Impedance Analysis: Principle, Equivalent Circuit Model, Applications in Electrode Characteristic Analysis, Applications in Al/LiCoO2/Electrolyte/Carbon/Cu Battery Analysis, Relative Permittivity, Ionic Conductivity, Diffusion Coefficient.

Unit 2: Material Characterization: Structural characterization techniques: X-ray Diffraction Analysis, Principle of X-ray Diffraction Analysis, Rietveld Refinement Spectroscopic techniques: FTIR Spectroscopy, Raman Spectroscopy, X-ray Photoelectron Spectroscopy, X-ray Absorption Spectroscopy (XAS) and X-ray Absorption Near-Edge Structure (XANES) Surface characterization Techniques: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) Thermal Analysis: Thermo-gravimetric analysis (TGA), differential thermal analysis (DTA) and differential scanning calorimetry (DSC).

Unit 3: Battery Design and Manufacturing : Battery Design: Battery Capacity, Electrode Potential and Battery Voltage Design, Design of Cathode/Anode Capacity Ratio, Practical Aspects of Battery Design Battery Manufacturing Process : Electrode Manufacturing Process , Preparation of Electrode Slurry, Electrode Coating , Roll Pressing Process , Slitting Process , Vacuum DryingProcess, Assembly and Winding Process

Unit 4: Battery Performance Evaluation: Charge and Discharge Curves of Cells, Significance of Charge and Discharge Curves, Adjustment of Charge/Discharge Curves, Overcharging and Charge/Discharge Curves, CycleLife of Batteries, Significance of Cycle Life, Factors Affecting Battery Cycle Life. Battery Capacity, Measurement of Battery Capacity, Discharge Characteristics by Discharge Rate, Temperature Characteristics, Low-Temperature Characteristics, High-Temperature Characteristics. Energy and Power Density (Gravimetric/Volumetric), Energy Density, Power Density

Unit 5: Application: Lithium-Ion Batteries for Storage of Renewable Energies and Electric Grid Backup: Residential Battery Storages in Combination with PV Systems-Variation of Lithium-Ion Battery Capacity, Quarter Battery Storages in the Distribution Grid. Li-Ion Batteries for Satellites: Main specifications, GEO Batteries' Requirements, LEO Batteries' Requirements, MEO Batteries' Requirements, Qualification Plans, Qualification Tests at the Cell Level, Qualification Tests at the Battery Level and Control of Production Quality. Solid-State Lithium-Ion Batteries for Electric Vehicles: Environment Surrounding Vehicles, Rechargeable Batteries for Automobile Use, Trends and Issues for Electric and HybridVehicles and Expectation toward Novel Li-Ion Batteries for Electric Vehicles. The Voltec System-Energy Storage and Electric Propulsion: Extended-Range Electric vehicles, Voltec Propulsion System, Voltec Drive Unit and Vehicle Operation Modes: Drive unit Operation and Driver Selectable Modes, Battery Operation Strategy.

Reference books:

1. Principles and Applications of Lithium Secondary Batteries, Jung-Ki Park, # 2012 Wiley-VCH Verlag & Co. KGaA,Boschstr, 12, 69469 Weinheim, Germany.

2. Lithium-Ion Batteries Advances and Applications by Gianfranco Pistoia , Elsevier 16th December 2013.

3. Impedance spectroscopy, theory and applications- J Ross Mc Donald, A John Wiley & Sons Inc., Publication, Second edition, 2005.

4. Handbook of Analytical Methods for Materials, Materials Evaluation and Engineering, Inc. 2016.

UE23PH842A: Quantum Computation

Course Objectives:

- To provide working knowledge of the protocols of quantum algorithms
- Apply quantum algorithms for database search and factoring problems
- To understand error correction mechanisms in quantum computation

Course Outcomes:

- Knowledge of quantum entanglement and basic logic of quantum cryptography
- Understanding of the structure and logic of quantum algorithms
- Working knowledge of Shor's and Grover's algorithm
- Understanding of the logic of quantum error correction codes

Course content

Unit 1: Entanglement and Quantum Information: Quantum parallelism and entanglement, the Bohm version of Einstein-Podolsky-Rosen paradox and Bell's inequality. No cloning theorem, dense coding, quantum teleportation and basic ideas of quantum cryptography and quantum key distribution.

Unit 2: Fundamental Quantum Algorithms: Query and communication complexity of quantum computation, the Oracle in quantumcomputation, Deutsch's problem and the Deutsch–Jozsa algorithm, Bernstein-Vazirani problem and Simon's problem, distributed computation.

Unit 3: The Quantum Fourier Transform and Factoring algorithms: The quantum Fourier transform, phase estimation, order finding and the hidden subgroup problem. Shor's factoring algorithm, classical extraction of the period from the measured value, discrete logarithm, example illustrating Shor's algorithm, the efficiency of the algorithm and generalizations.

Unit 4: Quantum Search Algorithms: The quantum search algorithms, Grover's quantum search algorithm, outline and set up, the iteration step, number of iterations, amplitude amplification and the geometric visualization. Optimality of Grover's algorithm, reduction to three inequalities, quantum counting, practical implications of quantum search algorithms.

Unit 5: Quantum Error Correction Codes: Framework for quantum error correcting codes, examples- code for correction of single bit fliperrors, code for single qubit phase flip error. Extension to three qubits. The Shor code. Encoding, transmission, error syndrome detection and correction, decoding.

References

1. Quantum Computing, A gentle introduction, E Rieffel and W Polak, The MIT Press, 2011.

2. Quantum Algorithms via Linear Algebra, A Primer, Richard J Lipton, Kenneth W Regan, The MIT Press, 2014.

3. Quantum Computation and Information, 10th Ed, Michael A. Nielsen and Issac L. Chuang Cambridge University Press, 2010.

4. Quantum Computer Science, N David Mermin, Cambridge University Press, 2007.

5. John Preskill's Lectures on Quantum Information and Computation, available at: http://theory.caltech.edu/people/preskill/ph229/]lecture;

UE23PH843A: Classical and Quantum Cryptography

Course Objectives

This course is designed to introduce the concepts and protocols of Classical and Quantum Cryptography. The students taking this course will

- Acquire the mathematical formalism of classical and quantum Cryptography
- Develop skills and methods of secure communication of information and key sharing
- Obtain an understanding of the basic quantum cryptographic protocols
- Analyze problems and threats related to the security of quantum cryptographic protocols

Course Outcomes

Students completing this course would be able to

- Understand and research the emerging ideas in the fields of cryptography and networksecurity.
- Implement various cryptographic protocols.
- Understand the implications of quantum computing on cryptography and security
- Understand the foundations of post-quantum cryptography

Course content

Unit 1: Mathematics of Cryptography: Modular Arithmetic Groups, Solving Modular Linear Equations, Chinese Remainder Theorem,Modular Exponentiation, Discrete Logarithm Problem; GCD Computation, Euclid's Algorithm, Extended Euclid's Algorithm, Euler's Phi-Function, Fermat's Little Theorem, Euler's Theorem, Generating Primes. Basic Cryptographic primitives: encryption, decryption,signatures, authentication.

Unit 2: Symmetric-Key Encipherment: Introduction, Symmetric Key Ciphers, Kerckhoff's Principle, Cryptanalysis, Categories of Traditional Ciphers Substitution cipher, onoalphabetic Ciphers, Polyalphabetic Ciphers. Transposition ciphers, Keyless Transposition Ciphers, Stream and block cipher Combination.

Unit 3: Asymmetric-Key Encipherment: Construction and Cryptanalysis, One-way function, Knapsack cryptosystem, RSA Cryptosystem, Different Attacks & Remedies on RSA, The Discrete Logarithm Problem (DLP), Diffie Hellman Key Exchange algorithm, Rabin Cryptosystem, The procedure and security of the Rabin system, The El Gamal Encryption Algorithm.

Unit 4: Quantum Cryptography: The implications of the uncertainty principle and Bell's theorem on information security, no cloning theorem. Information in quantum systems and representation. Quantum key distribution; examples, protocols, definitions, and concepts. Security against a classical eavesdropper, E91 Protocol, purifying protocols using entanglement.

Unit 5: BB84 Quantum Cryptographic Protocol : The BB84 quantum cryptographic protocol without noise, Stage 1. Communication over a quantum channel, Stage 2. Communication in two phases over a public channel. Phase 1 of Stage 2. Extraction of the raw key, Phase 2 of Stage 2. Detection of Eve's intrusion via error detection, The BB84 quantum cryptographic protocol with noise, Stage Communication over a quantum channel, Stage 2. Communication in four phases over a public channel. Post BB84protocol and trends in quantum cryptography.

References

1. Forouzan, Behrouz A. *Cryptography & network security*. McGraw-Hill Inc., 1st Edition.
2. Lomonaco, Samuel J. "A quick glance at quantum cryptography." *Cryptologia* 23.1 (1999): 1-41.
3. William Stallings, "Cryptography and Network Security Principles and Practices", Pearson/PHI, 7th Edition.
4. http://nptel.ac.in/courses/106105031/lecture by Dr. Debdeep Mukhopadhyay, IIT Kharagpur
5. https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-033-computer-system-engineering-spring-2009/video-lectures/ lecture by Prof. Robert Morris and Prof. Samuel Madden MIT.
6. Applied Quantum Cryptography, Editors**:** Kollmitzer, Christian, Pivk, Mario Springer.
7. Quantum Cryptography and the Future of Cyber Security (Advances in Information Security, Privacy, and Ethics),2020, Nirbhay Kumar Chaubey (Editor), Bhavesh B. Prajapati (Editor)

UE23PH844A: Quantum Mechanics and Quantum Logic Circuits

Course Objectives:

The course is structured to provide a basic structure and mathematical background for understanding quantum computation. The student will be exposed to the fundamental principles of quantum mechanics and the application of the idea of qubits and their representation in quantum logic circuits. The course will introduce the students to

- Hilbert space and Dirac notation and operator mechanics
- Postulates of quantum mechanics and the Schrodinger equation
- Qubits, Bloch sphere representation, pure and mixed states and the density operator
- Comparison between classical and quantum computation and the advantages of quantum computation
- Quantum logic circuits, reversible computation, unitary transformations and universal quantum logic gates

Course Outcomes:

Students completing this course would have

- a working knowledge of the application of linear vector spaces, matrices as operators and Eigen value equations as applied in quantum mechanics
- learnt the postulates of quantum mechanics and the idea of quantized states
- comprehensive logic of a multiple qubits, their representation and the significance of quantum superposition
- the understanding of the basic logic of classical computation and the advantages of quantum computation
- a working knowledge of quantum gates, their mathematical representation, quantum circuits and their application

Course content

Unit 1: Mathematical tools of Quantum Mechanics : Complex vector space, Hilbert space, dimension and basis, dual vector space, Dirac notation, inner product, orthonormal basis. Operators, Hermitian adjoint, projection operators, inverse and unitary operators. Features of Eigen values and Eigen functions of a Hermitian operator. Representation in discrete basis of vectors and operators. Change of basis and unitary transformations.

Unit 2: The Postulates of Quantum Mechanics: The Stern-Gerlach experiment, spin half systems, Mach-Zehnder interference, photon polarization states. Fundamental postulates of quantum mechanics, representation of a quantum state, superposition, dynamical variables-observables, operators, probability amplitude. The Schrodinger equation, solution to particle in an infinite potential. Energy quantization and normalization of the Eigen functions.

Unit 3: Single and Multiple Qubit Systems: Single qubit, multiple-qubit system, tensor products of vector spaces, dimensionality, relative and global phase, Bloch sphere representation. Ensemble of quantum states, pure and mixed states, the density matrix, general properties of the density operator, the reduced density operator. Mach-Zehnder interference in Dirac notation.

Unit 4: Classical Models of Computation and the Quantum Advantage: Turing machines, Boolean logic gates, circuits and operations. Quantification of classical resources, computational complexity. P and NP complexity classes. Energy and computation. Landauer's principle, irreversibility of computation and energy loss. Reversible computation and advantages of quantum computation.

Unit 5: Quantum Gates and Circuits: Quantum gates, quantum circuits, unitary matrix representation, reversibility. single qubit and multiple qubit gates, Pauli X, Y and Z transformations, Hadamard operator, Phase shift gates, controlled NOT X, controlled Z, Swap, Toffoli and other quantum logical gates, combinations and universal gates.

References

1. Quantum Mechanics, Concepts and Applications, Second Edition, N Zettili, Wiley, 2009.

2. Modern Quantum Mechanics, Revised Edition, J J Sakurai, Pearson Education Asia, 2002.

3. Quantum Computation and Information, 10th Edition, Michael A. Nielsen and Issac L. Chuang, Cambridge University Press, 2010.

4. Quantum Information and Computation, M Bellac, Cambridge University Press, 2006.