MSc ENERGY SCIENCE

Curriculum and Syllabus

त्यागेनैके अमृतत्वमानशुः

MATA AMRITANANDAMAYI MATH

श्रद्धावान् लभते ज्ञानम्

DEPARTMENT OF SCIENCES

AMRITA VISHWA VIDYAPEETHAM

COIMBATORE, TAMILNADU – 641112

INDIA

June 2021

SEMESTER 1			
Code No.	Course Title	L T P	Cr
21MAT506	Applied Mathematics	3 1 0	4
21PHY506	Science of Solids	3 1 0	4
21PHY507	Electromagnetic Theory	3 1 0	4
21PHY508	Quantum Mechanics and Statistical Mechanics	3 1 0	4
21PHY586	Energy Science Laboratory	0 0 4	2
	Elective A	3 0 0	3
21CUL501	Cultural Education	2 0 0	P/F
		TOTAL	**21**

SEMESTER 2			
Code No.	Course Title	L T P	Cr
21PHY516	Materials Science for Energy Applications	3 1 0	4
21PHY517	Electrochemistry,Energy Storage and Fuel Cells	3 1 0	4
21PHY518	Conventional Energy Sources	31 0	4
21PHY519	Energy Status, Energy Policy and Energy Audit	31 0	4
21PHY587	Project Based Laboratory	0 0 4	2
	Elective B	3 0 0	3
21AVP501	Amrita Value Programme	1 0 0	1
	TOTAL		**22**

SEMESTER 3			
21PHY606	Solar PV and solar thermal	3 1 0	4
21PHY607	Bio, Hydro and Wind Energy	3 1 0	4
21PHY608	Machine Learning for Energy Science	3 1 0	4
21PHY693	Mini Project		3
	Elective C	3 0 0	3
21LIV692@	Free / Open Elective / Live-in-Lab	2 0 0	2
TOTAL			**20**

SEMESTER 4			
21PHY695	Dissertation		12
	TOTAL		**12**
	TOTAL CREDITS		**75**

ELECTIVES

Code No	ELECTIVES	L T P	Cr
21PHY561	Nanoscience for energy applications	3 0 0	3
21PHY562	Physics Nuclear Energy	3 0 0	3
21PHY563	Optoelectronic devices	3 0 0	3
21PHY564	Thin Film technology	3 0 0	3
21PHY565	Sustainable chemical science	3 0 0	3
21PHY566	Fabrication of Advanced Solar cell: Understanding the device physics	3 0 0	3
21PHY567	Solar thermal engineering	3 0 0	3

Open Electives

Course Code	Course Title	L – T – P	Cr.	ES
21OEL631	Advanced Statistical Analysis for Research	2 0 0	2	D/E
21OEL632	Basics of PC Software	2 0 0	2	D/E
21OEL633	Computer Hardware and Networking	1 0 1	2	D/E
21OEL634	Consumer Protection Act	2 0 0	2	D/E
21OEL635	Corporate Communication	2 0 0	2	D/E
21OEL636	Design Studies	2 0 0	2	D/E
21OEL637	Disaster Management	2 0 0	2	D/E
21OEL638	Essentials of Cultural Studies	2 0 0	2	D/E
21OEL639	Foundations of Mathematics	2 0 0	2	D/E
21OEL640	Foundations of Quantum Mechanics	2 0 0	2	D/E
21OEL641	Glimpses of Life through Literature	2 0 0	2	D/E
21OEL642	Information Technology in Banking	2 0 0	2	D/E
21OEL643	Knowledge Management	2 0 0	2	D/E
21OEL644	Marketing Research	2 0 0	2	D/E

21OEL645	Media for Social Change	2 0 0	2	D/E
21OEL646	Media Management	2 0 0	2	D/E
21OEL647	Object-Oriented Programming	2 0 0	2	D/E
21OEL648	Painting and Sculpture	1 0 1	2	D/E
21OEL649	Personal Finance	2 0 0	2	D/E
21OEL650	Principles of Advertising	2 0 0	2	D/E
21OEL651	Principles of Packaging	2 0 0	2	D/E
21OEL652	Scripting for Rural Broadcasting	1 0 1	2	D/E
21OEL653	Social Media Website Awareness	1 0 1	2	D/E
21OEL654	Theatre Studies	1 0 1	2	D/E
21OEL655	Writing for Technical Purposes	2 0 0	2	D/E
21OEL656	Yoga and Personal Development	1 0 1	2	D/E
21OEL657	Fundamentals of Legal Awareness	2 0 0	2	D/E

* One Open Elective course has to be taken by each student, at 3rd semester, from the list of Open electives offered by the School.

@ Students undertaking and registering for a Live-in-Lab project can be exempted from registering for an Open Elective course in the fifth semester.

Program Objectives

To empower and enablestudents to acquire advanced knowledge and skills to contribute substantially in the field of Energy sector nationally and globally.

Programme Outcomes

PO1. **Science knowledge and problem analysis:**-. Develop analytical skills to identify, formulate, and analyze complex mechanisms using first principles of basic sciences.

PO 2. **Development of solutions:** Design solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development.

PO 3. **Communication:** Communicate effectively on complex scientific activities with science community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 4. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of scientific practice.

PO 5. **Project management and finance:** Demonstrate knowledge and understanding of scientific and management principles and apply these to one's own work, as a member and leader in a team, to manage projects in interdisciplinary environments

PO 6. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Programme Specific Outcomes

PSO 1: Solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation.

PSO 2: Understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society.

PSO 3: Will learn basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources.

	SEMESTER 1				
Code	**Course Title**	**L**	**T**	**P**	**Cr**
21MAT506	Applied Mathematics	3	1	0	4
21PHY506	Science of Solids	3	1	0	4
21PHY507	Electromagnetic Theory	3	1	0	4
21PHY508	Quantum Mechanics and Statistical Mechanics	3	1	0	4
21PHY586	Energy Science Laboratory	0	0	4	2
	Elective A	3	0	0	3
21CUL501	Cultural Education	2	0	0	P/F
	TOTAL				**21**

21MAT506	**Applied Mathematics**	**3 1 0 4**

Course Objectives:

1. Understand and revise the essential mathematics (mostly numerical procedures and linear algebra) necessary for presentation of data and optimization techniques necessary in this course
2. Refresh and be introduced to data analysis methods using statistical methods including hypotheses testing, regression, ANOVA etc.
3. Understand how to frame a problem in energy minimization as a mathematical optimization problem.

Unit 1: Linear Algebraic Equations and their solutions (Gauss-Jordan and Gauss-Siedel), Numerical techniques for ODEs (Euler method, Runge-Kutta method), other introductory numerical techniques including Taylor's series approximation of functions.

Unit 2: Introduction to Probability and Applied Statistics: Simple methods and ways of summarizing and presenting data: frequency distribution charts from the concept of probability; Mean, Variance, Skewness and Kurtosis and simple problems associated with data presentation.

Probability distributions: Random variables; Discrete distribution, continuous distribution; Moment generating functions and some examples of distribution functions and their characteristics: Binomial, Poisson, Geometric, Uniform, Exponential, Normal distribution Functions

Unit 3: Statistical Methods: Theory of estimation - point estimation, interval estimation, Testing of Hypothesis: Significance Test - test based on chi-square distribution & t & F distribution. Design and analysis of experiments-comparative experiments, Analysis of Variance (ANOVA), Design and analysis of experiments, factorial experiments.

Unit 4: Regression and Correlation analyses: Linear and non-linear regression (curve fitting), correlation parameters: covariance, correlation coefficient/coefficient of determination, r^2, adjusted r^2; Interpolation and extrapolation of data; Numerical implementation of regression and interpolation using EXCEL/Origin/Matlab or other programming language.

Unit 5: Optimization: Introduction to optimization techniques and difference from root finding techniques; Setting up an optimization problem: the Objective function and linear/non-linear constraints; One dimensional Unconstrained optimization: Golden Section search method, Parabolic interpolation, Newton's method, Brent's method; Multidimensional Unconstrained Optimization: Direct methods, Gradient methods; Constrained Optimization: Linear programming, non linear constrained optimization; Case studies: Least-cost design of a tank, Maximum power transfer in a circuit.

Text Books:

1. For Unit 1 and Unit 5: Numerical methods for engineers, Steven Chapra and Raymond Canale, Mc Graw Hill (6^{th}Ed.)
2. For Unit 2 and Unit 3: Schaum's Outline series on Probability and Statistics
3. For Unit 4: Numerical Methods for Engineers, Griffiths and Smith, Chapman & Hall/CRC press (2^{nd} Ed).

References:

1. Any good standard book on numerical methods (with a good chapter on minimization or optimization techniques)
2. Data reduction and error analysis for the physicist by Bevington and Richardson.
3. Any good book on applied statistics (many available in our library).

Course Outcomes:

On completion of the course the student should be able to:

CO 1	Represent systems in terms of linear algebraic equations and understanding the methodology of solving them, for material and conceptual representation in physical systems
CO 2	Understand and apply techniques of curve-fitting and interpolation, to aid in mathematical modeling of relationships between data
CO 3	Use statistical methods to do and also design experiments and report the results using a combination of graphical and numerical procedures
CO 4	Understand the concept of optimization and apply it for some simple systems based on minimizing or maximizing a function subject to constraints.

CO-PO Mapping:

CO/PO	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PSO 1	PSO 2	PSO 3
CO 1	2								
CO 2	2								
CO 3			2						
CO 4	1						2		

Evaluation Pattern:

Assessment	Internal	End Semester
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY506	Science of Solids	3 1 0 4

Course objectives:

The course gives an extensive knowledge on the crystal structure, bonding, and diffractions. It explains the formation of bands, electrical, thermal, and magnetic properties of solid-state materials. The course conveys an understanding of how solid-state physics has contributed to important technological developments of today.

Unit 1:
Learning Objectives:
After completion of unit-1, students will be able to:

1. Explain the crystallographic planes & directions of different crystal systems and point & space groups of respective crystal structure.
2. Explain the bonding in solids and nature of defects in crystals.
3. Recognize the correspondence between real and reciprocal space, and correlate the crystal diffraction pattern with respective reciprocal lattice.

Crystal Structure and Binding: Bravais lattices, crystal systems – point groups, space groups and typical structures, Reciprocal Lattice, Planes, and directions – Point, line, surface, and volume defects - Ionic crystals: Born Mayer potential. Thermochemical Born-Haber cycle – Van der Waals binding: rare gas crystals and binding energies, Covalent and metallic binding**:** characteristic features and examples.

Crystal Diffraction: X-rays, neutrons, electrons – Bragg's law in direct and reciprocal lattice – Structure factor – diffraction techniques.

Unit 2:
Learning Objectives:
After completion of unit-2, students will be able to:

1. Describe the phonon dispersion of monoatomic and diatomic lattices.
2. Explain the free electron theory of metals and electrical conductivity.
3. Reveal the contributions of phonons and electrons in thermal conductivity in solids.

Lattice dynamics: monoatomic and diatomic lattices. Born-von Karman method. Phonon frequencies and density of states. Dispersion curves, inelastic neutron scattering.

Thermal and electrical transport properties: Phonon heat capacity- Einstein and Debye Models. Thermal conductivity: Normal and Umklapp processes. Free electron theory of metals – Thermal and transport properties

Unit 3:
Learning Objectives:
After completion of unit-3, students will be able to:

1. Understand the effect of crystal potential on the electrons and describe the energy band formation in solids.
2. Detail the carrier statistics and conductivity in semiconductors.

Energy bands in solids: Bloch functions – Nearly free electron approximation – Formation of energy bands: Kronig- Penny Model, Brillouin zone, Effective mass, concept of holes, Tight Binding model, and Fermi surface.

Semiconductors: Band Gap, carrier statistics in intrinsic and extrinsic semiconductors, electrical conductivity, Hall Effect.

Unit 4:
Learning Objectives:
After completion of unit-4, students will be able to:

1. Discuss the photon absorption and luminescence phenomena in solids.
2. Explain the polarization and dielectric properties in solids.

Optical Properties: Optical absorption, photoluminescence, colorcenters, Traps, recombination, excitons, photoconductivity.

Dielectric Properties: Polarization, Macroscopic electric field, Local electric field in an atom, dielectric constant, and polarizability, Clausius-Mossotti equation, measurement of dielectric constant, Ferroelectrics.

Unit -5:
Learning Objectives:
After completion of unit-5, students will be able to:

1. Discuss the properties of superconductors and theories explaining the superconductivity.
2. Comprehensively describe the quantum theory of diamagnetism and paramagnetism in solids.
3. Explain the properties of ferromagnetic materials and reason out the different theories for the origin of ferromagnetism in solids
4. Describe the Ferrimagnetism and antiferromagnetism in solids

Superconductors: Experimental Results: Meissner Effect, Heat Capacity, Energy Gap. Type I and type II Superconductors, London Equations, Coherence Length, BCS theory, Flux quantization, Josephson effects, High Tc superconductors.

Magnetic Properties of solids: Types, Quantum theories of Diamagnetism and Paramagnetism. Ferromagnetic order: Hysteresis, Curie point and exchange integral, Magnons, domain theory. Ferri and antiferromagnetic order: Curie temperature, susceptibility, and Neel Temperature.

Reference books:

1. Charles Kittel, Introduction to Solid State Physics, Wiley Eastern, 8th edition, Reprint: 2016.
2. A.J. Dekker, Solid State Physics, Prentice Hall of India, 1971.
3. N.W. Ashcroft and N.D. Mermin, Solid State Physics, Saunders College Publishing, 1976.
4. Ali Omar, Elementary Solid State Physics, Pearson Education, 2002.
5. Ibach and Luth, Soil State Physics, Springer India, 3rd Edition, 2002.

Course Outcomes:
On completion of the course students will be able to:

1. Describe the crystal structure, bonding, defects, and diffraction.
2. Understand the lattice dynamics, free electron theory of metals and the thermal conductivity in solids.
3. Understand the basics approaches of band formation in solids and explain the carrier dynamics in semiconductors.
4. Develop comprehensive knowledge on the optical and dielectric properties of solids.
5. Acquire extensive understanding on the theories of magnetism and superconductors, elucidate the exchange interaction and domain theories of ferromagnetism.

CO-PO Mapping:

	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	-	-	-	-	2	-	-
CO2	3	2	-	-	-	1	2	-	-
CO3	3	2	-	-	-	1	2	-	-
CO4	3	2	-	-	-	-	2	-	-
CO5	3	2	-	-	-	-	2	-	-

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY507	Electromagnetic Theory	3 1 0 4

Prerequisite: NIL

Course Objectives: To give an overview of foundations of electromagnetic theory starts from electrostatics, magnetostatics and electrodynamics including potential formulations to students. Importance of Maxwell's equations in understanding electromagnetic waves and their propagation in different media, theory of wave guides will be highlighted. Knowledge on the theory of radiation and fundamentals of antennas will be imparted to students.

UNIT 1
Learning Objectives:
After completion of unit-1, students will be able to:

1. Explain basics of vector transformation under rotation, inversion operations, Vector calculus, orthogonal curvilinear coordinates and Dirac-Delta function.
2. Discuss electric field, electric potential, work and energy in electrostatics along with properties of conductors.
3. Explain electric fields in matter through the polarization phenomenon.

Review of Vector algebra and Vector calculus: Gradient, divergence, Curl and physical interpretation. Fundamental theorem for gradients, divergences and curls, Orthogonal Curvilinear coordinates, Dirac-Delta function. Electrostatic field, Divergence and curl of electrostatic field, Gauss law, Electric potential, Poisson's and Laplace equations, Work and energy in electrostatics, basic properties of conductors, Electrostatic boundary conditions, Electric fields in matter- Polarization, Field of a polarized object, Electric displacement and Linear dielectrics.

UNIT 2
Learning Objectives:
After completion of unit-2, students will be able to:

1. Recognize Biot-Savart law, Ampere's law, vector potential and use them to solve problems related to magnetostatics.
2. Discuss magnetic fields in matter through magnetization phenomenon.
3. Describe electromagnetic induction, Maxwell's equations and boundary conditions for electrodynamics.

Biot-Savart law, Ampere's law and its applications, Vector potential, Magnetization, Bound currents and physical interpretation, Auxiliary field, Electromotive force, Electromagnetic induction, Maxwell's equations, Boundary conditions for electrodynamics.

UNIT 3
Learning Objectives:
After completion of unit-3, students will be able to:

1. Recognize Poynting's theorem and conservations laws pertained to electrodynamics.
2. Analyze propagation of electromagnetic waves in different media by properly employing Maxwell's

equations.
3. Discuss the theory of wave guides.

Poynting’s theorem, Newton’s third law in electrodynamics, Conservation of linear and angular momentum, Waves in one dimensions, Electromagnetic waves in vacuum-wave equation for E and B, Monochromatic plane waves, Polarization, Energy and momentum in electromagnetic waves, Electromagnetic waves in matter-Reflection and transmission of electromagnetic wave at normal and oblique incidences, Rectangular wave guides-TE, TM modes and TEM mode in transmission lines.

UNIT 4
Learning Objectives:
After completion of unit-4, students will be able to:

1. Explain the importance of potential formulation in electrodynamics
2. Discuss Gauge Transformation and retarded potential concept

Potential formulation: Scalar and vector potentials, Gauge Transformation-Lorentz and Coulomb’s gauges, Retarded potentials, Jefimenko’s equations, Lienard-Wiechert potentials, thefields of a moving point charge.

UNIT 5
Learning Objectives:
After completion of unit-5, students will be able to:

1. Explain different sources of electromagnetic radiation.
2. Discuss the principles of half wave dipole antenna.

Electric dipole, Magnetic dipole radiations, Radiation from an arbitrary source, Principles of half wave dipole antenna, Types of antennas.

Reference Books:

1. D.J.Griffiths, Introduction to electrodynamics, Pearson Education India Learning Pvt. Ltd; 4^{th} Edition, (2015).
2. J.R. Reitz, F.J. Milford and R.W. Christy, Foundations of Electromagnetic Theory, 4^{th} edition, Pearson Education India (2010).
3. P. Lorrain and D. Corson, Electromagnetic Fields and Waves,CBS Publishers and Distributors, 2^{nd}edition (2003).
4. E.C. Jordon and K.G. Balmain, Electromagnetic Waves and Radiating Systems, 2nd edition, Pearson (2005).
5. J.D. Jackson, Classical Electrodynamics, Wiley, 3^{rd} Edition (2007).

Evaluation Pattern:

Assessment	Internal	End Semester
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

Course Outcomes:
After the completion of this course students will be able to:

CO1: understand basic aspects of electrostatics and electric field in matter
CO2: acquire knowledge in magnetostatics, magnetic field in matter and electrodynamics
CO3: analyze propagation of electromagnetic waves in different media using Maxwell's equations
CO4: understand electromagnetic potentials and gauge transformations
CO5: acquire knowledge related to the theory of radiation and antenna fundamentals

Skills: Improving analytical skills of students through solving problems related to electromagnetic theory given in the form of assignments and quizzes.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	-	-	-	2	2	-	-
CO2	3	2	-		-	2	2	-	-
CO3	3	2	-	-	-	2	2	-	-
CO4	3	2	-	-	-	2	2	-	-
CO5	3	2	-	-	-	2	2	-	-

21PHY508	Quantum Mechanics and Statistical Mechanics	3 1 0 4

Course objectives: The course emphasize the students to familiarize the fundamental concepts in quantum and statistical mechanics such as mathematical frame work of quantum theories, postulates, solvable problems in quantum mechanics, classical and quantum statistics and apply them in solving practical problems.

Course outcomes:
At the end of the course students will be able to:

CO1: Understand the fundamental postulates of Quantum Mechanics.
CO2: Apply Schrödinger's equations to solve basic quantum mechanical problems in one dimension spherically symmetric potentials and hydrogen atoms
CO3: Understand the significance of angular momentum operator and its applications
CO4: Understand the fundamental theories in Fermi Dirac and Bose Einstein Statistics and their applications
CO5: Apply FD statistics to get Fermi energy and Bose Einstein condensation etc.

Unit 1
Review of concepts in Quantum Mechanics (6 Hrs)
Inadequacy of classical theory, de-Broglie hypothesis, Heisenberg's uncertainty relation , Schrodinger's wave equation, physical interpretation and conditions on wave function, Eigenvalues and Eigen functions in quantum mechanics, particle in a square-well potential, potential barrier.

Unit 2
Postulates and their significance in Quantum mechanics (10 Hrs)
Significance of Operators and Eigen functions in Quantum mechanics, Linear operators, orthogonal systems and Hilbert space, expansion in Eigen functions, Hermitian operators, fundamental of commutation rule, commutations and uncertainties in operators, state with minimum uncertainty.

Unit 3
Solvable Problems in Quantum mechanics: **(15 Hrs)**
Harmonic oscillator – operator method, Schrodinger's equation for spherically symmetric potentials, Basics of angular momentum operator , condition on solutions and Eigenvalues, spherical harmonics – rigid rotor – radial equation of central potential, hydrogen atom – degenerate states.

Unit 4
Classical Statistical Mechanics (8 Hrs)
Relation between entropy and probability, Boltzmann's equation , elementary ideas about three different statistics, classical statistics – Maxwell & Boltzmann statistics, classical Ideal gas equation, equipartition theorem. Fermi-Dirac Statistics

Unit 5
Quantum statics (16 hrs)

Basics for quantum statistics: – system of identical indistinguishable particles – symmetry of wave functions – bosons, fermions, Fermi & Dirac statistics, Fermi free electron theory – Pauli Paramagetism.
Bose-Einstein Statistics Bose & Einstein statistics – black body radiation – Rayleigh Jeans' formula - Wien's law – Planck radiation law – Bose Einstein condensation – Einstein model of lattice vibrations – Phonons - Debye's theory of specific heats of solids.

References

1. P.M. Mathews and K. Venkatesan, A Textbook of Quantum Mechanics, Tata McGraw Hill (1977).
2. J.L. Powell and B. Crasemann, Quantum Mechanics, Narosa Publishing House (1993)
3. *N Zettili, Quantum Mechanics Concepts and Applications, John Wiley & Sons, 2E, 2009*
4. J.J. Sakurai, Modern Quantum Mechanics, Addison-Wesley (1999).
5. F. Reif, Fundamentals of Statistical and Thermal Physics, International Students Edition, Tata McGraw-Hill (1988).
6. K. Haung, Statistical Mechanics, Wiley Eastern (1991).

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	-	-	-	-	2	-	-
CO2	3	2	-		-	-	2	-	-
CO3	3	2	-	-	-	-	2	-	-
CO4	3	2	-	-	-	-	2	-	-
CO5	3	2	-	-	-	-	2	-	-

21PHY586	Energy Science Laboratory	004 2

Pre-requisite: Basics of physics and chemistry knowledge in undergraduate level.

Course Objective:

To provide fundamental knowledge and hands on experience on experiments related to Energy Science.

Course Outcomes: After completion this course student will be able to:

CO1 Apply basic knowledge of electricity and magnetism to find Hall Coefficient, resistivity and type of charge carriers in bulk materials and thin films, analyze and present the results.

CO2 Relate principles of absorption spectroscopy and diffraction, to find absorption spectrum, band gap and structural details of nanostructures, and draw conclusions from obtained data and present.

CO3 Execute electrochemical impedance spectroscopy foranalyzing capacitance, charge transfer resistance and Warburg impedanceof dielectrics.

CO 4 Perform energy related experiments and analyze the results and present.

Skills: Hands on experience with experiments related to X-ray diffraction, ESR, UV-Vis. Spectroscopy, and energy conversionwhich improve experimental skills of students.

1. Hall Effect experiment.
2. Van der Pauw method of Four-probe method: Measurement of resistivity and Hall coefficient of fabricated thin film.
3. Verification of Beer-Lambert's law using UV-Vis. Spectroscopy.
4. Analysis of XRD spectrum using database.
5. Band gap determination of semiconducting nonmaterial using UV-Vis. spectroscopy.
6. Electrochemical impedance spectroscopic analysis of capacitors, secondary batteries, dielectric materials and evaluation of capacitance, charge transfer resistance and Warburg impedance.
7. Estimation of composition in waste.
8. Measurement of calorific value of solid, liquid and gaseous fuels.
9. Estimation of energy content of a given conventional fuel (coal / LPG).
10. Pyrolysis /gasification of biomass (or waste).
11. Case study of a biogas production from food waste.
12. Energy conservation of a wind turbine.
13. Efficiency calculation from solar cell.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	3	-	2	-	2	-	2
CO2	3	2	3	-	2	-	2	-	3
CO3	3	2	3	-	2	-	3	-	2
CO4	3	2	3	-	2	-	3	-	3

	SEMESTER 2				
Course Code	**Course Title**	**L**	**T**	**P**	**Cr**
21PHY516	Materials Science for Energy Applications	3	1	0	4
21PHY517	Electrochemistry,Energy Storage and Fuel Cells	3	1	0	4
21PHY518	Conventional Energy Sources	3	1	0	4
21PHY519	Energy Status, Energy Policy and Energy Audit	3	1	0	4
21PHY587	Project Based Laboratory	0	0	4	2
	Elective B	3	0	0	3
21AVP501	Amrita Value Programme	1	0	0	1
	TOTAL				**22**

21PHY516	**Materials Science for Energy Applications**	3 1 0 4

Unit 1: Introduction to materials, structure of materials, classification of materials Metals, Ceramics, Polymers, Composites and their Types, Crystal Defects: Point Defects, Frenkel and Schottky Defects, Line and Planar Defects, Grain Boundaries; Diffusion in Solids, Solid Solutions, Intermetallics; Cooling Curves and Phase Diagrams: Isomorphous and Eutectic Phase Diagrams. Electrical Conduction in Solids, Resistivities of Mixed Solid Phases, Hall Effect; Polarization and Permittivity, Piezoelectricity, Ferroelectricity, and Pyro electricity; Magnetic properties and Superconductivity, Optical Properties of Materials: Reflection, Refraction, Dispersion, Refractive Index, Snell's Law, Light Absorption and Emission, Light Scattering, Luminescence, Polarization, Anisotropy, Birefringence.

Unit 2: Materials processing: Metals and Alloys, Ceramics, Polymers, Thin films.

Unit 3: Materials characterization: Atomic and Molecular Spectroscopy: Atomic Absorption, Fluorescence and Emission Spectroscopy, UV-Visible Spectroscopy, Infrared Spectroscopy, Raman Spectroscopy, Energy Dispersive X-ray Spectroscopy, X-ray Photoelectron Spectroscopy, Nuclear Magnetic Resonance Spectroscopy, Mass Spectrometry; Imaging Microscopies and Image Analysis: Optical Microscopy, Scanning Electron Microscopy, Scanning Probe Microscopy, Image Analysis; thermal analysis, DSC, TGA.

Unit 4: Nanomaterials science: Introduction to nanotechnology and nanomaterials science, properties of nanomaterials, fabrication of nanomaterials, top down and bottom up methods-sputtering – ALD – MBE. Concepts of quantum and phonon confinement, optical and vibrational properties of nanomaterials. Carbon nanomaterials, CNT, C60 graphene, CQD, application of nanomaterials in energy conversion, nanofabrication in Si solar cell, Thin fim solar cell, DSSC, PEC and H2 generation. Nanomaterials for energy storage.

Text Books and References:

1. D. Askeland, P. Fulay, W. J. Wright and K. Balani, "The Science and Engineering of Materials", Sixth Edition, Cengage, 2012.
2. D. Jiles, "Introduction to the Electronic Properties of Materials", Chapman & Hall. 1994.
3. M. P. Groover, "Principles of Modern Manufacturing", Fifth Edition, SI Version, Wiley India, 2014.
4. M. D. Ventra, S. Evoy and J. R. Heflin, "Introduction to Nanoscale Science and Technology", Kluwer Academic Publishers, 2004.

Course Outcomes:

At the end of the course Students will be able to**:**

CO1: Understand various types of materials used in the energy applications.

CO2: Understanding the electrical and optical properties of the energy related materials.

CO3Understand the fundamental principles behind the individual characterization methods, analyze, interpret and present observations from the different characterization methods

CO4: Comprehend various nanostructured materials and their energy related applications

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	-	-	-	-	2	-	-
CO2	3	2	-		-	-	3	-	-
CO3	3	2	-	-	-	-	2	-	-
CO4	3	2	-	-	-	-	3	-	-

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY517	Electrochemistry, Energy Storage and Fuel Cells	3 1 0 4

Course objectives: To understand the fundamental principles of electrochemistry and its application in electrochemical energy systems and processes.

Course outcomes:
On completion of the course students will be able to:

CO1: Understand the conducting properties of electrolytes and the quantitative aspects of electrochemical reactions.
CO2: Analyze the properties of electrodes and the thermodynamics of electrochemical reactions.
CO3: Understand the principles of electroanalytical techniques and its application in different fields.
CO4: Apply electrochemistry for the development of energy storage devices and electrochemical processes.

Skills: To apply the principles of electrochemistry for the development of energy storage devices and electrochemical processes relevant to industries.

Unit 1: Fundamentals of Electrochemistry: Quantitative Electrochemistry-Review of Faraday's laws, conductivity of electrolytes, ionic mobility, transference number, Kohlrausch law, Ostwald dilution law. Deviations from the Ostwald law, Modern theory of conductance of strong electrolytes and its tests and improvements, Debye-Huckel-Onsager equation – theory of mean activity coefficients of strong electrolyte – Mass Transfer in Electrolytes – Convection, Diffusion, and Migration, conductometric titrations.

Unit 2: Electrified Interface: Interfacial region – electrical double layers and their structure – Helmholtz Perrin, Gouy-Chapman and Stern models – charge transfer across interfaces, Electrode potential and its measurement, Electrochemical cells, standard electrode potentials, reversible cell, cell notation and calculation of emf – variation of potential with concentration, pressure and temperature, applications of potential measurements, Reference electrodes, potentiometry, pH metry, Faradaic and Non-Faradaic processes, Polarization of Electrodes – Activation, Concentration and IR overpotential, Electrode Kinetics – Butler-Volmer Equation, Tafel Equation.

Unit 3: Electroanalytical Techniques: Potential Step Methods – Chronoamperometry, Potential Sweep Methods – Linear SweepVoltammetry and Cyclic Voltammetry: Reversible, Quasi-reversible, and Irreversible Systems; Pulse Voltammetry – Normal Pulse, Differential Pulse, and Square Wave Voltammetry; Electrochemical Impedance spectroscopy; applications of electroanalytical techniques, Electrodeposition of metals and Alloys, Corrosion, Batteries, Fuel Cellsand Electrochemical Sensors.

Unit4: **Electrochemical processes**: Industrial cathodic processes, Electrodeposition of copper, nickel and chromium over mild steel – zinc plating on MS, Industrial Anodic Processes: Anodising of aluminium and its alloys, electropolishing – Electrochemical etching of ferrous and non-ferrous metals, electrochemical machining, electroless deposition- – making of waveguides and plated through hole boards.

Unit 5: Introduction to energy storage, need for energy storage and different modes of energy storage. Characteristics and performance evaluation, Design and Construction of batteries, Electrochemical Energy storage, Principle of working and construction– Supercapacitors, Materials for Supercapacitors, Batteries, Electrolytes, Primary batteries, Leclanche, Duracell and Lithium primary batteries, LeadAcid Batteries, Nickel-Metal Hydride batteries, Silver peroxide zinc battery, Lithium-Ion Batteries and Lithium polymer batteries, Sodium batteries, Thin-film Batteries, Redox flow batteries, MetalAirBatteries, Reserve batteries, Energy Storage for Fuel Cells; Hydrogen storage- Hydrogen Economy, Different modes ofhydrogen storage, compressed gas storage, liquid hydrogen storage, metal hydrides, Direct methanol fuel cells, Molten carbonate fuel cells, Biofuel cells.

Text Books and References

1. *Electrochemical Methods: Fundamentals and Applications, Allen J Bard and Larry Faulkner,* Wiley; 2nd edition.
1. Industrial Electrochemistry, Pletcher, D., Walsh, F.C, Springer, *An introduction to Electrochemistry, Samuel Glassstone (*2007)
2. John O'M. Bockris,Amulya K.N .Reddy, Maria E. Gamboa-Aldeco, Modern Electrochemistry 2A: Fundamentals of Electrodics 2nd Edition, Springer, 2001
3. Tetsuya Osaka, Madhav Datta, "Energy Storage Systems in Electronics", 1st ed., CRC Press, 2000.
4. David Michael Rowe, "Thermoelectrics Handbook: Macro to Nano", CRC Press, 2006.
5. Thomas Reddy, Linden's Handbook of Batteries, 4th Edition, McGraw-Hill Education

Evaluation Pattern:

Assessment	Internal	End Semester
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can have Quizzes, Assignments and Seminar.

CO-PO Mapping:

PO/CO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2	2				3	2	
CO2	3	2	2				3	2	
CO3	3	3	2				2	2	2
CO4	3	2	2				2	2	2

21PHY518	Conventional Energy Sources	3 1 0 4

Course objectives:

1. To understand the science of thermal power generation
2. To describe the fundamental physics behind nuclear fission, nuclear fusion and radioactive decay and understanding on reactor physics and engineering aspects.
3. To understand the various stages of nuclear fuel cycle, from mining and manufacture to reprocessing and disposal.
4. To describe the current status of nuclear reactors and key safety issues associated with nuclear power generation
5. The course seeks to impart knowledge on fossil fuels and their combustion characteristics
6. To make students inquisitive about the problems of combustion and arousing their interest on practical problem related to combustion process.

Course outcomes:

On completion of the course students will be able to:

CO1: Understand the Physics and technology of thermal power generation.

CO2:Acquired knowledge on nuclear physics and correlates the knowledge to nuclear power generation.

CO3: Development of knowledge on combustion process and application of combustion process on energy generation.

Skills: To apply the principles of electrochemistry for the development of energy storage devices and electrochemical processes relevant to industries.

Unit 1:

Thermal Power: the physics of power plants (Steam and gas power cycles); General layout of modern thermal power plant, Site selection, Presents status of power generation in India.High Pressure Boilers & AccessoriesCoal & Ash Handling SystemsCondensers and Cooling Towers. Feed Water Treatment. Diesel Power Plant. Pollution and its Control

Unit 2:

Nuclear Reactor Physics : Nuclear fission and chain reaction; Neutron thermalisation; Neutron diffusion equation; Reactor kinetics and reactor dynamics; Monte Carlo methods; Nuclear fuel cycle and nuclear waste management; Reactor types and future Generation IV reactors; Accelerator Driven Systems and transmutation; Basic principles and modern issues of nuclear power safety. Radiation, Protection, Dosimeter and Detectors. Radiation Damage in Materials. Nuclear Reactor Dynamics and Stability. Numerical Methods in Nuclear Energy. Nuclear Power Safety

Unit 3:

Oil and Natural Gas Technologies: Origin and Occurrence of Hydrocarbons; Rock and Fluid Properties-reservoir science; Oil Reservoirs; Gas Reservoirs; Flow; Drilling; Safe Transportation of Petroleum Products and Natural Gas ;Oil Spill Clean-Up; Pollution control

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO 1	2	3	2			3	3	2	
CO 2	2	3	2			3	3	2	
CO 3	2	3	2			3	3	2	

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY519	Energy Status, Energy Policy and Energy Audit	3 1 0 4

Course Objectives:

1. To facilitate the student on the present status of energy scenario.
2. To develop the knowledge on clear conceptual understanding of technical and commercial aspects of energy conservation and energy auditing.
3. To enable the students to develop managerial skills to assess feasibility of alternative approaches and drive strategies regarding energy conservation and energy auditing.

Unit 1: Global Energy Scenario; world energy outlook, internationalprotocols for energy and environment, governing and nodal national/internationalagencies and their role. Import and export position, Resources, Reserves, Indian Energy Scenario, Energy Security - Concept, Trade-Off between Energy Securityand Climate Change.

Unit 2: Energy Policy: (The state of energy and the symbiosis between energy, policy, technology, and the economy; Importance; The consequences of using Energy; economic, environmental, societal; Electricity market -production -economics; liquid fuels- market -production -economics Economics/Policy of Renewable- challenges for implementations, impact on climate change, ; The policy of energy efficiency; politics of climate change; future of energy policy)

Unit 3: Energy Audit, Need for energy audit, Difference betweenenergy audit and energy management.Basic concepts in energy audit, Methodology for energy audit, Energy audit in buildings, Energy audit in industrial plant.
Case studies

Text Books and References:

1. TF Braun & MG Lisa. Understanding Energy and Energy Policy. Zed Books,(2014) ISBN 1780329342.
2. Industrial Energy Management and Utilisation; L.C.Witte, P.S.Schmidt, D.R.Brown, Hemisphere Publ, Washington, 1988.
3. Industrial Energy Conservation Manuals, MIT Press, Mass, 1982.
4. I.G.C.Dryden, Butterworths, The Efficient Use of Energy, London, 1982
5. W.C.Turner, Wiley, Energy Management Handbook, New York, 1982

Course Outcomes:
On completion of the course students will be able to:

CO1: Ability to understand the present energy demand and energy production in world and India.
CO2. Conceptual knowledge of the technology, economics and regulation related issuesassociated with energy conservation and energy auditing.
CO3. Ability to analyze the viability of energy conservation projects.

CO4. Capability to integrate various options and assess the business and policy environmentregarding energy conservation and energy auditing.

CO5. Advocacy of strategic and policy recommendations on energy conservation and energyauditing.

CO-PO Mapping:

	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	3	3	-	-	-	3	3	2
CO2	3	2	3		3	3	2	3	
CO3	3	2	-	-	3	-	2	-	-
CO4	3	3	3	-	3	-	2	2	-
CO5	3	2	3	-	3	-	2	3	-

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY587	Project Based Laboratory	0042

Pre-requisite: Fundamentals of basic physics and chemistry along with the knowledge on electrochemistry, electrodynamics, solid state sciences, and quantum mechanics.

Course Objective:

To provide preliminary knowledge on science behind energy harvesting and energy storage device along with the hands on experience for materials fabrication and properties for energy applications.

Course Outcomes: After completion this course student will be able to:

CO1 Apply the knowledge of materials fabrication and properties and device fabrication for energy application.

CO2 Correlates the knowledge on science of solids, electrochemistry with experimental results.

CO3 Hands on experience on energy harvesting and energy storage device fabrication.

CO4 Organize, analyze results and draw conclusions, document technical report and orally presentthefindings.

Skills: Hands on experience with experiments related to materials fabrication, X-ray diffraction, electron microscopy, ESR, UV-Vis. Spectroscopy, Florescence spectroscopy, impedance spectroscopy and electrometer, which improve experimental skills of students.

1. Fabrication and testing of Dye sanitized solar cell – Using source meter and electrochemical work station.
2. Fluorescence spectroscopy of materials
3. Dielectric spectroscopy studies on materials
4. I-V characteristic of metal sulfide/iodide/oxide films
5. Fabrication of super capacitor electrodes and testing
6. Quantum dot based LED fabrication
7. Identification of defects in carbon – Raman Study.
8. Experiment on fuel cell
9. Simulation studies of material property.
10. Cyclic voltammetry of purely reversible system ferricyanide, Evaluation of diffusion coefficient and the mechanism.
11. PEC experiment of TiO_2 based electrode.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	3	3	-	3	3	2	3	3
CO2	3	3	3	-	2	3	2	-	3
CO3	2	2	3	2	3	3	3	3	3
CO4	3	-	3	3	3	2	2	-	-

	SEMESTER 3				
Course Code	**Course Title**	**L**	**T**	**P**	**Cr**
21PHY606	Solar PV and Solar Thermal	3	1	0	4
21PHY607	Bio, Hydro and Wind Energy	3	1	0	4
21PHY608	Machine Learning for Energy Science	3	1	0	4
21PHY693	Mini Project				3
	Elective	3	0	0	3
21LIV692@	Free/Open Elective / Live-in-Lab	2	0	0	2
	TOTAL				**21**

21PHY606 Solar PV and Solar Thermal 3 1 0 4

Unit 1: Solar energy: Solar radiation, its measurements and analysis. Solar angles, day length, angle of incidence on tilted surface, Sun path diagrams, Shadow determination. Extraterrestrial characteristics, Effect of earth atmosphere, measurement & estimation on horizontal and tilted surfaces. Types of solar energy converters, Requirements of an ideal photo-converter, Principles of a solar cell design, material and design issues; Revisions of Semiconductor Physics, Physics of semiconductor Junctions; p-n junction under dark and under illumination, effect on junction characteristics, other device structures. Photovoltaic cell and power generation, Characteristic of the Photovoltaic Cell.

Unit 2: Silicon Solar cell, Mono -crystalline and poly–crystalline cells, Metallurgical Grade Si, Electronic Grade Si, wafer production, Mono–crystalline Si Ingots, Poly–crystalline Si Ingots, Si–wafers, Si–sheets, Solar grade Silicon, Si usage in solar PV, Commercial Si solar cells, process flow of commercial Si cell technology, Process in solar cell technologies, Sawing and surface texturing, diffusion process, thin film layers, Metal contact.

Unit 3: 2nd generation solar cell, Thin film solar cell,Advantage of thin film, Thin film deposition techniques, Evaporation, Sputtering, LPCVD and APCVD, Plasma Enhanced, Hot Wire CVD, closed space sublimation, Ion Assisted Deposition, Substrate and Super -state configuration, Thin film module manufacturing, Thin film and Amorphous Si Solar cell, Cadmium Telluride Solar Cell, CIGS solar Cell, CZTS solar cell, New materials for thin film solar cell. Optics in solar energy conversion: antireflection coatings, concentration of light: Light confinement, photon recycling, multiple exciton generation.

Unit 4:3rd generation Solar cell; Advances in Photovoltaics, Photochemical and photosynthetic energy conversion; DSSC,, Solution processed thin film, Organic Solar Cell, Hydride Perovskite solar cell and multijunction tandem solar cells. Solar photovoltaic system design: Solar cell arrays, system analysis and performance prediction, shadow analysis, reliability, solar cell array design concepts, PV system design, Design process and optimization, Detailed array design, storage autonomy, Voltage regulation, maximum tracking, Power electronic converters for interfacing with load and grid, use of computers in array design, Quick sizing method, Array protection and troubleshooting;

Unit 5: Solar Thermal systems: Solar thermal collectors, flat plate collectors, concentrating collectors, solar heating of buildings, solar still, solar water heaters, solar driers; conversion of heat energy in to mechanical energy, solar thermal power generation systems.

Text Books and References:

1. Physics of Solar cells-Jenny Nelson, Imperial College Press (2006)
2. Crystalline Silicon Solar Cells, by A. Goetzberger, J. Knobloc h, and B. Voss (Wiley, 1998)
3. Third Generation Photovoltaics: Advanced Solar Energy Conversion, by M. A. Green (Springer, 2006)
4. Semiconductor Materials for Solar Photovoltaic Cells; Paranthaman, M.P. (et al.) (Eds.) (2016)

Course Outcomes:
On completion of the course students will be able to:

CO1. Understand the science of solar cell.
CO2: Calculate the solar radiation at a given location, time and tilt.Compare the methods of synthesis and characterization of different solar cells basedon Si, GaAs, InP, III-V, II-VI multi-junctions.
CO 3. Design simple photovoltaic systems
CO 4 Outline the solar thermal devices and systems
CO 5: Understand the basic science of recent trend in solar PV and solar thermal technology.

CO-PO Mapping:

CO/PO	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PSO 1	PSO 2	PSO 3
CO 1	3	3	2				3	2	3
CO 2	3	2	2				3	3	3
CO 3	3	2	2				2	2	3
CO 4	2	2					2	2	3
CO5	3	2	2				3	2	3

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can have Quizzes, Assignments and Seminar.

21PHY607	Bio, Hydro and Wind Energy	3 1 0 4

Course Objectives:

- Learn principles of extraction of energy from biomass and water
- Design bio and hydro power conversion systems
- Learn principles of tidal, wave and ocean thermal energy conversion

Unit 1: Energy from biomass: sources, classification, conversion into fuels, photosynthesis, C3 and C4 plants on biomass production, physicochemical characteristics; CO2 fixation potential. Biomass resource assessment, biomass productivity study, waste land utilization through energy plantation. Biomass conversion process: biochemical - anaerobic digestion, biogas production mechanism and technology, types of digesters, design of biogas plants; chemical - hydrolysis and hydrogenation, bio-fuels, Biodiesel production, fuel characteristics; thermochemical - pyrolysis, combustion and gasification, gasifiers: updraft, downdraft, fluidized bed, biomass carbonization, natural draft and gasification based biomass stoves, gasification based power generation.

Unit 2: Design of power plants. Hydrology, Selection of site, Resource assessment, Classification of Hydropower Plants, Small Hydropower Systems: mini, micro and pico systems, Pumped storage plants, Hydraulic Turbines: classification and operational aspects, elements of turbine, selection and design criteria, Planning of power house, Hydro power from oceans – Wave and Tidal power, Electronic load controller; environmental issues related to hydro projects

Unit 3: Meteorology of wind: Global circulation, Forces influencing wind, Local Wind systems, Wind Speed modeling – Weibull parameters and estimation, Wind Rose. Wind Turbines: Types, Rotor elements; Horizontal and vertical axis wind turbines, Power in the wind, Power extracted from wind, Betz limit, Lift and drag coefficients, thrust and torque, stream tube model, linear momentum theory, power coefficient, thrust coefficient, axial interference factor. Pitch and stall regulation, power curve, and energy calculation. Wind turbine generators: stand alone systems – schemes and system design, grid-connected systems – types, topology, characteristics, fixed speed and variable speed systems. Power electronic interface. Brakes.Gears. Wind farm development and operation: Techno economic feasibility. Government regulations and guidelines, micrositing and layout, use of software in micrositing, selection of equipment, installation and commissioning. Local infrastructure and power evacuation, influence of grid quality and reliability. Operation and maintenance. Central monitoring system and SCADA. Windfarm performance indices.Economic performance indices. Offshore wind farm development and special considerations. Short term and long term Wind forecasting. Grid code for wind farm operation.

Text Books and References:

1. Sorensen B., “Renewable Energy”, Second Edition, Academic Press, 2000.
2. Ravindranath N. H. and Hall D. O., “Biomass, Energy and Environment”, Oxford University Press, 1995.
3. Rosillo-Calle F. and Francisco R., “The Biomass Assessment Handbook: Bioenergy for a SustainableEnvironment”, Earthscan, 2007.
4. M. M. Dandekar and K. N. Sharma, “Water Power Engineering”, Vikas Publishing House Pvt. Ltd., Second Edition, 2014.

5.Joshua Earnest and Tore Wizelius, “Wind Power Plants and Project Development”, PHI Learning Pvt. Ltd., New Delhi, 2011.
6.G L Johnson, “Wind Energy Systems”, Manhattan, KS, 2004.
7. ErichHau, “Wind Turbines- Fundamentals: Technologies, Application, and Economics”. Springer – VerlagBerlin -Heidelbeg, 2000.

Course Outcomes:
On completion of the course students will be able to:

CO1 Understanding the science of energy extraction from biomass and water.
CO2 Familiarity with various biomass conversion processes.
CO3 Knowledge on design of bio and hydro power generation systems.
CO4Understanding of wind resources, principles of conversion and technologies.

CO-PO Mapping:

CO/PO	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PSO 1	PSO 2	PSO 3
CO 1	3	3				3	3	3	3
CO 2	3	3				2	3	3	3
CO 3	2	3				2	3	3	3
CO 4	3	3				2	3	3	3

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can have Quizzes, Assignments and Seminar.

21PHY608	Machine Learning for Energy Science	3 1 0 4

Course Objectives:

- Basic understanding of machine learning and Artificial Intelligence
- Prospect of machine learning for energy efficiency and sustainability.
- Software knowledge on energy management

Unit1

Background and theory of AI, machine learning for energy applications, available tools for AI applications in the energy sector, fundamental concepts of inference and prediction, opportunity and limitations of machine learning, Motivation and methods for inferential machine leaning methods, Dimensionality Reduction and Clustering, predictive machine learning methods, k Nearest Neighbors, Prediction: Tree-based Regression, ensemble methods, neural network.

Unit 2

Renewable Energy Forecasting, prediction model, statistical model, AI based model, hybrid model, prediction of solar irradiance, prediction of wind energy and hydro energy.

Unit 3

Machine learning for smart grid, Introduction to smart grid, Smart Grid–Need, Definitions, Concept, Functions & Barriers. Present development & International scenario in Smart Grid. Smart Grid – System architecture and Stakeholders. Communication Technologies for Smart Grid, Interoperability, Protocols, Standards for Information Exchange. Information Security in smart grid, Cyber Security standards. Smart grid management by machine learning, Future energy systems and software.

Unit 4: Case study or group project.

Text Books and References:

1. Machine Learning for Energy Systems; ISBN 978-3-03943-382-7 (Hbk); ISBN 978-3-03943-383-4 (PDF); Denis N. Sidorov (Ed.) https://www.mdpi.com/books/pdfview/book/3201

2. Internet of Energy for Smart Cities; Machine Learning Models and Techniques; Edited By Anish Jindal, Neeraj Kumar, Gagangeet Singh Aujla; ISBN 9780367497750; July 20, 2021 Forthcoming by CRC Press; 322 Pages 112 B/W Illustrations

Course Outcomes:
On completion of the course students will be able to:

CO.1 Understanding the fundamentals of machine learning and AI.
CO.2 Familiarity with various methods of machine learning
CO.3 Energy efficiency and Smart grid management by machine learning
CO.4 Understanding of the renewable energy forecasting by machine learning.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2		-	-	-	2	-	-
CO2	2	2	-		-	-	2	-	-
CO3	3	3	2	-	2	3	3	3	2
CO4	3	3	2	-	2	3	2	3	3

Evaluation Pattern:

Assessment	Internal	End Semester
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

21PHY693	Mini Project	3

The proposed mini project work will get initiated at the beginning of the third semester. The students are required to choose the area of their project work and conduct literature survey / simple experimental/ simulation methods under the guidance of a faculty. The students are expected to work on a topic in the field Energy Science. They will be evaluated based on the presentations made by them and a report submitted at the end of the semester by a committee of examiners appointed by the Chairman of the Department.

Course Outcomes:

CO 1 Identify a research topic their area of interest in Energy Science.
CO 2 Conduct a systematic literature review, identify gaps and define objectives and scope of work.
CO 3 Develop methodology for prototype/model/experimental setup necessary for the work.
CO 4 Document the technical report and orally present the project work.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2				-	2	2	-
CO2	3	3	2		2	2	3	2	2
CO3	3	3	2	3	3	2	3	3	2
CO4	3		3	3	-	-	2		

SEMESTER 4

21PHY695	Dissertation	12

The dissertation should be focused on the synthesis of knowledge gained over the past three semesters and mini project. The dissertation should be relevant to Energy Science which could involve theoretical and / or computational and / or fabrication and/ or experimental work. If the project is carried out at other institutions/ laboratories / industries, their experts are to be associated in choosing the research topic and its execution.Students are required to document the results and submit a report at the end of the semester. Evaluation will be done during the course of the project as well as at the end of the semester by a committee of examiners appointed by the Chairman of the Department.

Course Outcomes:

CO1 Identify a research topic and conduct thorough literature survey and define objective and scope of work.
CO2 Develop methodology for conducting the theoretical/experimental study.
CO3 Plan, manage and execute experimental work to obtain results with a concern for safety, industry and environment.
CO4 Organize, analyze results and draw conclusions, document technical report and orally the present findings.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	3				-	2	2	-
CO2	3	3	2		2	2	3	2	2
CO3	3	3	2	3	3	2	3	3	2
CO4	3		3	3	-	-	2		

ELECTIVES

Course Code	Course Title	L T P	Cr
21PHY561	Nanoscience for energy applications	3 0 0	3
21PHY562	Physics Nuclear Energy	3 0 0	3
21PHY563	Optoelectronic devices	3 0 0	3
21PHY564	Thin Film technology	3 0 0	3
21PHY565	Sustainable chemical science	3 0 0	3
21PHY566	Fabrication of Advanced Solar cell: Understanding the device physics	3 0 0	3
21PHY567	Solar thermal engineering	3 0 0	3

21PHY561	Nanoscience for Energy Applications	3 0 0 3

Prerequisite: Basics of solid state physics and electrochemistry in undergraduate level.

Objectives:

- To understand difference between bulk and nanomaterials and various properties of nanostructures and synthesis procedures
- To comprehend quantum and phonon confinements and concept of excitons in nanostructures
- To understand various nanostructured materials and their energy related applications
- To comprehend solar energy conversion with nanoscale structures, energy storage science and storage devices using nanostructured materials

Course Outcomes:
After completion of the course, students will have knowledge and skills to:

CO 1. Understand difference between bulk and nanomaterials and various properties of nanostructures and synthesis procedures.
CO 2. Understand quantum and phonon confinements and concept of excitons in nanostructures.
CO 3. Comprehend various nanostructured materials and their energy related applications.
CO 4. Apply knowledge and describe the working of solar energy conversion devices, and energy storage devices.

Skills: Working ofvariousnanostructures based energy conversion and storage devices, fabrication techniques. Testing efficiency of the devices and ways to improve the efficiency.

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	3					3		
CO2	3	2					3		
CO3	3	3					2		
CO4	3	3	2			3	2		2

Unit 1:
Learning Objectives:

1. To understand difference between bulk and nanomaterials
2. To comprehend the properties of nanomaterials
3. To understand various synthesis techniques of nanostructures

Nanomaterials science: Introduction to nanotechnology, comparison of bulk and nanomaterials-surface energy and surface tension and relation to size, phase transformation in nanomaterials, specific heat and heat capacity of nanomaterials, mechanical, optical, electrical and magnetic properties of nanomaterials-synthesis of nanomaterials - classification and fabrication methods- top down and bottom up methods-sputtering – ALD – MBE.

Unit 2:
Learning Objectives:

1. To understand concepts of quantum and phonon confinement in 2D and 3D
2. To comprehend the multiple excitons generation

Concepts of quantum and phonon confinement: Basic concepts - excitons, effective mass, free electron theory and its features, band structure of solids. Bulk to nano transition - density of states, quantum confinement effect - weak and strong confinement regime. Electron confinement in infinitely deep square well, confinement in two and three dimension. Blue shift of band gap, Effective mass approximation. Vibrational properties of Solids - Phonon Confinement effect and presence of surface modes. Multiple excitons generation.

Unit 3:
Learning Objectives:

1. To understand various types of nanostructures and their properties
2. To comprehend the applications of nanostructured materials

Nanostructured Materials: Properties and Applications. Carbon nanotube - structure,electrical, vibration and mechanical properties. Applications of carbon nanotubes -Field emission and Shielding - computers - Fuel cells - Chemical sensors - Catalysis -Mechanical reinforcement. Quantum dots and magnetic nanomaterials – applications.

Unit 4:
Learning Objectives:

1. To understand solar energy conversion in various nanostructures
2. To comprehend the working of various energy conversion devices

Energy conversion in nanoscale structures: Size effects in light-matter interactions, 0D, 1D and 2D quantum confined functional materials for solar energy conversion, size driven advantages and disadvantages of functional materials in devices, charge carrier dynamics at nanoscale in energy conversion devices.In Si solar ARC, DSSC, PEC, H2 generation and storage-LED by QD- application

Unit 4:
Learning Objectives:

1. Using basics of electrochemistry, understand energy storage concepts and devices using nanomaterials
2. To comprehend the electrochemical methods

Energy storage science and energy storage devices using nanomaterials: Introduction to electrochemistry, potentials and thermodynamics of cells, galvanic and electrolytic cells, kinetics of electrochemical reactions, mass transfer by migration and diffusion, non-Faradaic and Faradaic reactions. Nanomaterials as anode and cathode for batteries and electrochemical capacitors, advanced batteries with nanoscale materials and surface/interface modifications, liquid and solid electrolytes, cycle-life, capacity, energy and power density assessments, safety concerns and solutions.

Electrochemical methods: Potentiostatic and galvanostatic, cyclic voltammetry, chronoamperometry, chronopotentiometry and electrochemical impedance.

Text Books:

1. Robert W. Kelsall, Ian W. Hamley and Mark Geoghegan, Nanoscale Science and Technology,John Wiley and Sons Ltd 2004.
2. W.R. Fahrner (Ed.), Nanotechnology and Nanoelectronics, Springer 2006.

Reference Books:

1. Charles P. Poole, Jr.Frank J. Owens, “Introduction to nanotechnology”, A John Wiley 81 Sons,Inc., Publication
2. T. Pradeep, “Nano the essentials understanding nanoscience and nanotechnology”, Professor, Indian Institute of Technology, Madras, Chennai, India.
3. Jenny Nelson, “The Physics of Solar Cells”, First Edition, Imperial College Press, 2003.
4. Stephen Fonash, Solar Cell Device Physics - 2nd Edition, Academic Press,2010.
5. L. R. Martinez and N. Omar, Emerging Nanotechnologies in Rechargeable Energy Storage Systems, 1st Edition, Elsevier (2017).
6. G. A. Nazri and G. Pistoia, Lithium Batteries, Springer, 2009.
7. Allen Bard and Larry R. Faulkner, Electrochemical Methods, John Wiley & Sons Inc, 2001.

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be quizzes, assignments, projects, and reports.

Course objectives:

The objectives of the course is to:

- Impart essential fundamentals of atomic and nuclear physics
- Introduce nuclear energy and nuclear physics fundamentals such as half-value thickness for neutron beam attenuation, nuclear cross sections, neutron flux and fluence, nuclear reactors and material selection criteria for nuclear components.
- Introducethe primary radiation damage during neutron–nucleus collision and subsequent primary knock-on atom and lattice atoms interaction; and its effect on properties of non-fuel reactor materials.
- Impart knowledge on various types of nuclear fuels and structural, physical, mechanical and corrosion properties.
- Give basic knowledge on the beneficial effects of radiation and stable radioactive isotopes, radiation protection and handling of radioactive waste.

Course outcomes:
At the end of the course, the students will be able to:

CO1: Apply the fundamental physical concepts of atomic and nuclear physics to interpret the design and operation of nuclear reactors.
CO2: Explain the sustained neutron chain reaction, different types of reactors and reactor components.
CO3: Describe the radiation damage and their influence on properties of non-fuel reactor materials.
CO4: Discuss different types of metallic and ceramic fuels, their fabrication technique, properties and advantages.
CO5: Describe the biological effects of radiation and benefits; principles of reactor safety; radiation hazards and protection; and handling of nuclear wastes.

Skill acquired: Students acquire analytical skills to evaluate the half-value thickness for neutron beam attenuation, nuclear cross sections, and neutron flux and fluence and output power of nuclear reactors by applying first principles of basic sciences of nuclear fuel, nuclear components and nuclear radiation. Besides, acquire basic knowledge on different types of nuclear fuels, applications of stable radioisotopes and radiations; threshold radiation exposure and radiation induced damage and the preventive measures.

Unit I **(5 hrs)**

Learning Objectives:

After completion of unit-1, students will be able to:

- Explain the atomic and nuclear properties such as their radius, molecular weight, energy equivalence of mass, density and their stability.

Review of Basic concepts of Atomic and Nuclear Physics: Fundamental particles, Atomic and nuclear structure, Atomic and molecular weight, Atomic and nuclear radii, Mass and energy, particle wavelengths, excited states and radiation, nuclear stability and radioactive decay, radioactivity calculations, nuclear reactions, binding energy, nuclear models: shell mode, liquid drop model.

Unit II **(15 hrs)**

Learning objectives:

After completion of unit-1I, students will be able to:

- Explain different types of nuclear energy
- Describe the interaction of neutron with matter and determine the half-value thickness for neutron beam attenuation, nuclear cross sections, neutron flux and fluence.
- Explain the different type of nuclear reactors and can select appropriate materials for reactor components.

Types of Nuclear Energy: Nuclear Fission Energy, Nuclear Fusion Energy, Radioisotopic Energy; Neutron Classification, Neutron Sources, Interactions of Neutrons with Matter: Fission Chain Reaction, Neutron Flux and Fluence, Neutron Cross Section: Reactor Flux Spectrum, Nuclear heat energy, Types of Reactors: A Simple Reactor Design, Generation-I,II,III and IV Reactors, Boiling Water Reactor (BWR), Pressurized Water Reactor (PWR), CANDU Reactor, RMBK Reactor, Fast Breeder Test Reactor, Fusion Reactor,Materials Selection Criteria, Reactor Components: Structural/Fuel Cladding Materials, Moderators and Reflectors, Control Materials, Coolants, Shielding Materials, Fusion Reactors.

Unit III **(15 hrs)**

Learning objectives:

After completion of unit-1II, students will be able to:

- Discuss the primary radiation damage involving neutron–nucleus collision and subsequent PKA and lattice atoms interaction leading to the formation of displacement cascades.
- Evaluate the displacement threshold, damage displacement rate and displacement per atom.

Radiation Damage, Radiation Effects on non-fuel reactor Materials: Microstructural Changes: Cluster Formation, Extended Defects, Nucleation and Growth of Dislocation Loops, Void/Bubble Formation and Consequent Effects, Radiation-Induced Segregation, Radiation-Induced Precipitation or Dissolution; Mechanical Properties: Radiation Hardening, Saturation Radiation Hardening, Radiation Anneal Hardening (RAH), Channeling: Plastic Instability, Radiation Embrittlement, Effect of Composition and Fluence, Effect of Irradiation Temperature, Effect of Thermal Annealing, Helium Embrittlement, Irradiation Creep, Radiation Effect on Fatigue Properties; Radiation Effects on Physical Properties: Density, Elastic Constants, Thermal Conductivity, Thermal Expansion Coefficient; Radiation Effects on Corrosion Properties: Metal/Alloy, Protective Layer, Corrodent, Irradiation-Assisted Stress Corrosion Cracking (IASCC)

Unit IV **(15 hrs)**

Learning objectives:

After completion of unit-1V, students will be able to:

- Explain different types of nuclear fuels and their fabrication techniques
- Describe the properties of metallic and ceramic fuels and their advantages

Nuclear Fuels: Metallic Fuels: Uranium, Plutonium and Thorium, and their fabrication structure, physical, mechanical and corrosion properties, Ceramic Fuels: Ceramic Uranium Fuels, Uranium Dioxide, Uranium Carbide, Uranium Nitride, Plutonium-Bearing Ceramic Fuels, Thorium-Bearing Ceramic Fuels.

Unit V **(10 hrs)**

Learning objectives:
After completion of unit-V, students will be able to:

- Explain the biological effects of radiation.
- Describe the application of stable isotopes, nuclear propulsion and nuclear radiation protection measures.
- Differentiate different types of radioactive wastes and their mode of disposal.

Biological Effects of Radiation, Applications of Isotopes and Radiation, Reactor Safety, Nuclear Propulsion, Radiation Protection: Protective Measures, Calculation of Dose, Effects of Distance and Shielding, Internal Exposure, The Radon Problem, Environmental Radiological Assessment, Newer Radiation Standards, Radioactive Waste Disposal.

Textbooks:

1. Lamarsh, J.R. and Baratta, A.J., 2001. *Introduction to nuclear engineering* (Vol. 3, p. 783). Upper Saddle River, NJ: Prentice hall. (Unit I, unit II)
2. Murty, K.L. and Charit, I., 2013. *An introduction to nuclear materials: fundamentals and applications*. John Wiley & Sons. (Unit II, III& IV)
3. Murray, R.L. and Holbert, K.E., 2008. An Introduction to the Concepts, Systems, and Applications of Nuclear Processes. *Nuclear Energy*, *6*. (Unit V)

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be quizzes, assignments, projects, and reports.

CO-PO mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	-	-	-	-		-	-	-	1	-	-
CO2	3	3	-		-	-	-	-	-	3	-	-
CO3	3	3	-	-	-	-	-	-	-	3	-	-
CO4	3	3	-	-	-	-	-	-	-	3	-	-
CO5	3	3	-	-	-	-	-	-	-	3	-	-

21PHY563	Optoelectronic Devices	3 0 0 3

Course objective:

The aim of this course is to provide students with the knowledge to understand the operating principles and practical devices features of semiconductor-based optoelectronic devices.The coursealsointroduces the basic concepts of optical waveguides, optical switches, and modulators.

Course Outcomes:

On completion of the course, students will be able to

CO1. Realize the nature of semiconducting materials, their growth and the energy bands
CO2. Develop knowledge on the carrier dynamics and the mechanism of absorption, photoluminescence and photoconductivity in semiconductors which are used in energy applications.
CO3. Understand the formation and working of *p-n* homojunction and heterojunctions for energy applications
CO4. Gain knowledge on the theory and operation of optoelectronic devices, optical wave guides, optical switches, and modulators.

CO-PO Mapping:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2					3		
CO2	3	2					3		
CO3	3	2					3		
CO4	3	2				2	3	3	3

Unit 1
Learning Objectives:
After completion of unit-1, students will be able to

4. Describe the crystal structure of technological important semiconductors.
5. Explain the bulk and epitaxial growth techniques of semiconductor crystals.

Introduction: Semiconductor materials; Crystal lattices; Bulk Crystal growth, epitaxial growth.

Unit 2
Learning Objectives:
After completion of unit-2, students will be able to

1. Understand the nature of the energy bands and variation in the bandgap energy with respect to the composition of the semiconducting alloys.
2. Brief the carrier transport in the semiconductors.

Energy bands and Charge carriers in Semiconductors: direct and indirect semiconductors; variation of Energy bands with alloy composition. Charge carriers in semi-conductors-electrons, holes, effective mass; intrinsic and extrinsic materials. Drift of carriers in electric and magnetic fields.

Unit 3
Learning Objectives:
After completion of unit-3, students will be able to

1. Understand the concept of excess carriers and optical absorption process in semiconductors.
2. Explain the photoluminescence and electroluminescence process.
3. Brief the diffusion of carriers, current-voltagecharacteristics in *p-n* junction and study.

Excess carries in Semiconductors: Optical absorption; luminescence – photoluminescence, electroluminescence. Carrier lifetime and photoconductivity, diffusion of carriers. P-N Junction Diode: Current-Voltage Characteristics; heterojunctions.

Unit 4
Learning Objectives:
After completion of unit-4, students will be able to

1. Discuss the working principle of Light emitting diodes and Lasers
2. Describe the operating characteristics of different photodetectors and solar cells

Optoelectronic Devices: Principle of operation and characteristics of Light emitting diodes, lasers, photo detectors, solar cells; Relevance of III-V and IV-VI material- systems in optoelectronic devices

Unit 5
Learning Objectives:
After completion of unit-5, students will be able to

1. Understand the working of quantum well electro-absorption modulators and the electro-optic modulators
2. Appreciate the working principles of optical switching and logic devices

Integrated Optics: Optical waveguides - passive, electro-optical; optical modulators and switches; optical storage devices.

TEXTBOOK:
Pallab Bhattacharya, "Semiconductor Optoelectronic Devices", 2nd Edition, Pearson Education.

REFERENCE BOOKS:

1. S.O. Kasap, " Optoelectronics and Photonics – principles and practices" second edition, Pearson Education Limited, 2013.
2. Jasprit Singh, "Semiconductor Optoelectronics: Physics and Technology", First edition , McGraw Hill Education, 2019.
3. Wilson and Hawkes, "Optoelectronics; An Introduction", 2nd Ed., PHI.
4. Hummel R E, "Electronic Properties of Materials", Narosa Publishing House, New Delhi.

Evaluation Pattern:

Assessment	Internal	End Semester
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be quizzes, assignments, projects, and reports.

Pre-requisite: none

Course Outcomes

At the end of the course, students will be able

CO1. To understand the principle, differences and similarities, advantages, and disadvantages of different thin film deposition methods.

CO2. To evaluate and use models for understanding nucleation and growth of thin films.

CO3. To analyze thin film properties to apply for various applications.

CO4. To improve problems solving skills related to evaluation of different properties of thin films.

Skills: Presentations and problem solving in the form of assignments on different thin film growth techniques improve both analytical and presentation skills of students.

CO-PO-PSO mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
CO1	1	2													2	
CO2	1	2													2	
CO3	1	2	2	2											2	
CO4	1	2	2	2											2	

Unit 1

LO1: understand about the various physical and chemical deposition methods

Preparation methods: Physical methods: thermal evaporation, cathodic sputtering,Molecular beam epitaxy and laser ablation methods. Chemical methods: electrolytic deposition, chemical vapour deposition.

Unit 2

LO1 understand the principle in measuring the thickness of thin films and to find a suitable method for measuring the thickness of thin films.

LO2-Understand and analyze the characteristics of thin films using different instrumentation technique.

Thickness measurement and Characterization: Electrical, mechanical,optical interference, microbalance, quartz crystal methods.

Analytical techniques of characterization: X-ray diffraction, electron microscopy, high and low energy electron diffraction, Auger emission spectroscopy.

Unit 3

LO1: able to understand the nucleation theories leading to the growth.
LO2: able to understand different types of growth mechanisms in the growth of thin films
LO3-Understand, analyze and treating the Structural defects in thin films.

Growth and structure of films: General Features-Nucleation theories – Effect of electronbombardment on film structure – Post-nucleation growth - Epitaxial film growth - Structural defects.

Unit 4

LO1: Understanding the mechanical behavior of thin films.
LO2: Understanding and calculating the optical constants of thin films and hence draw the conclusions regarding the optical behavior of thin films.
LO3: understanding he electrical and superconducting behavior of thin films and hence to draw a valuable conclusion regarding the properties of the material

Properties of films: Mechanical properties: elastic and plastic behavior.

Optical properties – Reflectance andtransmittance spectra - Absorbing films - Optical constants of film material -Multilayer films - Anisotropic and isotropic films.

Electric properties to films: Conductivity in metal, semiconductor and insulating films - Discontinuous films - Superconducting films.

Unit 5

LO1: Understanding the theories of magnetism and the application of magnetic thin films in various fields.
LO2: understanding the working principle of thin film devices and the fabrication and application of thin film devices.

Magnetism of films: Molecular field theory - Spin wave theory - Anisotropy in magneticfilms - Domains in films - Applications of magnetic films.

Thin film devices: fabrication and applications.

TEXTBOOKS:

1. K.L. Chopra, Thin Film Phenomena, McGrawHill (1983).

2. George Hass. Physics of Thin Films: Volumes 1':12. Academic Press (1963).

REFERENCE BOOKS:

1. K.L. Chopra and I.J. Kaur, Thin Film Solar Cells, Plenum Press (1983).

2. L.I. Maissel and Giang (Eds.), Handbook of Thin film Technology, McGrawHill (1970).

3. J.C. Anderson, The Use of Thin Films in Physical Investigation, Academic Press (1966).

4. J.J. Coutts, Active and Passive Thin Film Devices, Academic Press (1978).

5. R.W. Berry, P.M. Hall and M.T. Harris, Thin Film Technology, Van Nostrand (1968). 47

21PHY565	Sustainable Chemical Science	3 0 0 3

Pre-requisite: UG level course on green chemistry

Course Objectives:

1. To recognize the interconnection between green chemistry and sustainability.
2. To assimilate concepts in water based chemical reactions and green solvents.
3. To understand that practicing catalytic reactions directly corresponds to green chemistry.
4. To understand the correlation between alternate energy sources and green technologies.

Keywords: Green chemistry, Sustainable Chemistry, green solvent, catalytic reactions, alternate energy sources

Course Outcomes (CO)

At the successful completion of the course, the student will be able to

Name	Description
CO1	To demonstrate 12 principles of green chemistry in terms of sustainable metrics and green toxicology
CO2	Reproduce the chemistry practised in water and green solvents
CO3	Elucidate working of catalysts and catalysed reactions.
CO4	Effectively use alternate energy sources in carry out chemical reactions.

Skill development: Innovation is the call of the day and green chemistry will help develop requisite skills for innovative reaction schemes for sustainable applications.

Programme Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	2	0	0	0	0	0	0	1	0
CO2	0	2	0	0	0	0	0	0	0
CO3	1	0	0	0	0	0	0	0	0
CO4	0	2	0	0	0	0	3	0	1

Justification

Mapping	Justification	Affinity level
CO1-PO1	CO1 has a direct confluence with PO1, since it provides solutions to complex chemical problems with modern analytical tools. The amounts of affinity level is 2	2
CO2-PO2	The student will be learning the application of green solvents for industrial process leading to safer environment and health. An affinity level of 2 is given for the direct correlation.	2

CO3-PO1	The student will be learning different catalysts and their working and reactor conditions. Hence, they have a direct correlation of 1 with PO1	1
CO4-PO2	Green chemistry has an indispensable workmanship with sustainable development. Hence a direct correlation is characterized. Since no advanced tools are used in quantifying sustainability an affinity level of 2 is assigned.	2
CO4-PSO1	Requirement of alternate energy source to produce energy in a sustainable manner has a direct correlation of 3 with PSO1.	3
CO1-PSO2	Green chemistry principles are applied to produce sustainable energy.	1
CO4-PSO3	Utilize alternate energy sources for conducting chemical reaction.	1

Unit 1 Green Chemistry and Sustainability

Learning objective 1: Understand the history and 12 principles of green chemistry.

Learning objective 2: Understand green toxicology.

History of green chemistry, Chemical composition of the, environment (Air, water & soil- Role of organic and inorganic molecules in pollution), the twelve principles of green chemistry (detailed description with examples), green chemistry as an expression of environmental ethics (Thrift Chemistry), the concept of sustainability, from green to sustainable chemistry, sustainable use of chemical feedstock, water and energy, quantifying greenness of a chemical reaction, green chemistry metrics- mass based, energy and environmental metrics, designing greener process, life cycle assessment (introduction and scope), Green toxicology- the need, principles of toxicology, Disposition of Toxicants in Organisms, Non-Organ System Toxicity, Mechanistic Toxicology, Quantitative Structure–Activity Relationships, (Environmental Toxicology-Persistence and bioaccumulation), Non-Cancer risk assessment, Cancer risk assessment, stakeholders in sustainable policy implementation.

Unit 2Chemistry in water

Learning objective 1: Understand hydrophobicity and its importance in water-based chemistry.

Learning objective 2: Understand the basics of green oxidation and reductions.

Learning objective 3: Understand the importance of water in microwave and ultrasonic technology.

Definition and attributes of a green solvent, the principle and reasons for use of water in green chemistry-hydrophobicity-cyclodextrin chemistry, Lewis acids in aqueous media, Michael addition in water using triflates, green processes with base in water, green oxidations and reduction in water, on water conditions, use of water in microwave and ultrasonic technology.

Unit 3Green solvents

Learning objective 1: Understand notation, properties and synthesis of ionic liquids and certain name reactions using them.

Learning objective 2: Understand the properties of super critical fluids and study certain name reaction.

Learning objective 3: Understand the working of green solvents like polyethylene glycol, glycerol, cyclopentyl methyl ether, 2-methyltetrahydro furan, Perfluorinated (Fluorous) Solvents- FluorousBiphase Concept and dimethyl carbonate.

Ionic liquids as green solvents- definition and notation- properties, synthesis and use in organic reactions, oxidation, oxidative carbonylation of aniline, Friedel–crafts reaction, Michael addition, Fischer Indole synthesis, Benzoin condensation, dimethyl carbonates synthesis in ionic liquids.

Super critical fluids- super critical water and carbon dioxide- properties and organic transformations. (Diels Alder, Clasen rearrangement, Fisher Indole, Friedel–crafts reaction, oxidation and hydrogenation.

Properties and application in organic transformation of green solvents like polyethylene glycol, glycerol, cyclopentyl methyl ether, 2-methyltetrahydro furan, Perfluorinated (Fluorous) Solvents- FluorousBiphase Concept and dimethyl carbonate.

Unit 4 Green Chemistry and Catalysis

Learning objective 1: Understand the working of catalytic system (homogeneous, Heterogeneous and Biocatalysis).

Learning objective 2: Understand various catalyst preparation and characterization methods.

Importance of catalysis, turn over number and frequency, the basis of catalysis-kinetic phenomenon, basics of homogeneous, heterogeneous and biocatalysis, sabatier's principle, catalyst -deactivation, sintering, thermal degradation, inhibition and poisoning, catalyst promoters, modifiers, supported catalysts and reagents for green chemistry- heterogenized reactions for green chemistry, preparation of solid catalyst-slurry and co-precipitation, impregnation, hydrothermal synthesis- drying, calcination, activation and forming, selecting the right support, catalyst characterization- surface characterization methods, temperature programmed techniques, spectroscopy and microscopy. Common mechanism in enzyme catalysis immobilized enzymes, developing biocatalyst- rational design and directed evolution, non-enzymatic biocatalysts.

Unit 5 Green Chemistry Technologies and Alternate Energy Sources

Learning objective 1: Understand photochemical processes 9advantages and challenges).

Learning objective 2: Understand microwaves as energy source in chemistry.

Learning objective 3: Understand the relationship between sonochemistry and green chemistry.

Learning objective 4: Understand electrochemical synthesis.

Learning objective 5: Understand renewable energy scenario pertaining to India.

Design for Energy Efficiency, Photochemical Reactions Advantages of and Challenges Faced by Photochemical Processes (Examples)

Microwaves as energy source in chemistry- properties of microwaves, microwave heating (Effects), Approaches to Microwave-assisted Organic Chemistry- solvent free methods, MORE chemistry, continuous microwave reactor (CMR)-microwave batch reactor (MBR), examples of organic transformations.
Sonochemistry and Green Chemistry-Theoretical Basis- Cavitation Inception, Nucleation-Bubble Dynamics-examples of organic transformations, Sono-chemical synthesis of nano-structured materials,
Electrochemical Synthesis- materials manufactured using the process, organic electrosynthesis- 3-bromothiophen from thiophene
Renewable Sources of Energy, Solar Energy, Wind Power, Geothermal Solution, Hydropower (Sources, Merits and Difficulties in widespread applications), Indian Energy scenario- Energy Conservation act (2001)- features.

Reference

1. Green chemistry and engineering A Pathway to Sustainability, Anne E. Marteel-Parrish, Martin A. Abraham, American Institute of Chemical Engineers, Inc, John Wiley & Sons, Inc 2014.
2. Synthetic organic Sonochemistry, Jean-Louis luche, Springer Science+Business Media New York, 1998
3. New Methodologies and Techniques for a Sustainable Organic Chemistry, Alessandro Mordini and FerencFaigl, Springer, 2008.
4. Green chemistry, Fundamentals and Applications, Suresh C. Ameta and RakshitAmeta, CRC press, Taylor & Francis Group, 2013
5. Handbook of Green Chemistry, Vol5 Green Solvents- Reactions in Water, PualT Anastas, Chao Jun Li
6. Sonochemistry: theory, reactions, syntheses, and applications, Filip M. Nowak, Nova Science Publishers, Inc, 2010.
7. Green Chemistry Metrics, A Guide to Determining and Evaluating Process Greenness, Dicks, Andrew, Hent, Andrei, SpringerBriefs in Green Chemistry for Sustainability, 2015
8. Catalysis: concepts and applications, Gadi Rothenberg,Wiley-VCH Verlag& Co. KGaA, Weinheim, Germany, 2008

Evaluation Pattern

Assessment	Internal	External
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
Continuous Assessment (CA)	20	
End Semester	-	50

21PHY566	Fabrication of Advanced Solar cell: Understanding the device physics	3 0 0 3

Pre-requisites: Basic understanding of semiconductor physics.
Course Objectives: This course is developed to educate the student on recent trends on the solar cell fabrication and the device structure. So the student should learn the different technique of solar cell fabrication from materials to device.

Course Outcomes

At the end of the course students will be able to

CO1: Understand thedifferent method of solar energy harvesting like solar thermal solar thermal power and solar PV.

CO2: Understand the working principle of solar PV, Physics behind photo current and photo voltage generation in solar cell.

CO3: Fabricate different types of solar cell with considerable efficiency.

CO4: follow the recent trends and current research focus on the fabrication of solar cell.

Skills: Fabrication of solar cell, characterization of solar cell, development of solar cell.

CO-PO Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3	2				2	3	3	3
CO2	3	2				2	3		3
CO3	3	3			2	3	2		3
CO4	1	2				2	2	2	3

UNIT 1

Learning Objectives:

After completion of unit-1, students will be able to
LO1 - Basic understanding of Si solar cell
LO2 - Know about different type of solar energy harvesting
LO3 - Developing knowledge on semiconductor physics for PV applications
LO4 - Basic understanding of Solar PV

The Solar Resource and types of solar energy converters, Requirements of an ideal photoconverter, Principles of a solar cell design, material and design issues; Revisions of Semiconductor Physics, Physics of semiconductor Junctions; p-n junction under dark and under illumination, effect on junction characteristics, Other device structures. Photovoltaic cell and power generation, Characteristic of the Photovoltaic Cell.

UNIT 2

Learning Objectives

After completion of unit-2, students will be able to
LO1: Basic knowledge on Si solar cell
LO2: Single crystal Si solar cell structure
LO3: Single crystal Si solar cell Fabrication
LO4: Basic knowledge on thin film solar cell
LO5: knowledge on CIGS solar cell
LO6: Knowledge on CdTe solar cell

Silicon Solar cell, Mono -crystalline and poly–crystalline cells, Metallurgical Grade Si, Electronic Grade Si, wafer production, Mono–crystalline Si Ingots, Poly–crystalline Si Ingots, Si–wafers, Si–sheets, Solar grade Silicon, Si usage in solar PV, Commercial Si solar cells, process flow of commercial Si cell technology, Process in solar cell technologies, Sawing and surface texturing, diffusion process, thin film layers, Metal contact.

UNIT 3

Learning Objectives

After completion of unit-3, students will be able to
LO1 - Basic Knowledge on Thin Film Solar cell

2nd generation solar cell, Thin film solar cell, advantage of thin film, Thin film deposition techniques, Evaporation, Sputtering, LPCVD and APCVD, Plasma Enhanced, Hot Wire CVD, closed space sublimation, Ion Assisted Deposition, Substrate and Super -state configuration, Thin film module manufacturing, Thin film and Amorphous Si Solar cell, Cadmium Telluride Solar Cell, CIGS solar Cell, CZTS solar cell, New materials for thin film solar cell.
Optics in solar energy conversion: antireflection coatings, concentration of light: Light confinement, photon recycling, multiple exciton generation.

UNIT 4

Learning Objectives

After completion of unit-4, students will be able to
LO1 – Knowledge on DSSC

3rd generation Solar cell; Advances in Photovoltaics, Photochemical and photosynthetic energy conversion; DSSC,, Solution processed thin film, Organic Solar Cell, Hydride Perovskite solar cell and multijunction tandem solar cells;
Solar PV modules: Series and Parallel connections, Mismatch between cell and module, Design and structure, PV module power output, PV system configuration, standalone system with DC / AC load with and without battery, Hybrid system, Grid connected systems.

UNIT 5

Learning Objectives

After completion of unit-5, students will be able to

LO1 – Development of expertise on device fabrication

Hand on experience on solar cell fabrication, DSSC fabrication, Perovskite solar cell fabrication, Thin film solar cell fabrication.

TEXT BOOKS / REFERENCES:

1. Physics of Solar Cells-Jenny Nelson, Imperial College Press (2006)

2. Crystalline Silicon Solar Cells, by A. Goetzberger, J. Knobloc h, and B. Voss (Wiley, 1998)

3. Third Generation Photovoltaics: Advanced Solar Energy Conversion, by M. A. Green (Springer, 2006)

4. Semiconductor Materials for Solar Photovoltaic Cells; Paranthaman, M.P. (et al.) (Eds.) (2016)

Evaluation Pattern:

Assessment	Internal	External
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be Quizzes, Assignments, Projects, and Reports.

Pre-requisites: Basic understanding of thermodynamics and heat transfer.

Course Objectives:

- Learn the concepts of thermodynamics and heat transfer in buildings, heat exchangers.
- Design solar thermal collectors for various applications and evaluate performance.

Course Outcomes

At the end of the course students will be able to

CO1: Understanding of the concepts of thermodynamics and heat transfer.

CO2: Ability to apply the principles of thermodynamics in energy transfer.

CO3: Ability to analyze and evaluate heat transfer in buildings and heat exchangers.

CO4: Ability to apply principles to collect and measure the solar thermal form of energy.

Skills: Fabrication of solar thermal collector, development of solar thermal collector.

CO-PO Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PSO1	PSO2	PSO3
CO1	3					2	2		1
CO2	3	2				2	2		2
CO3		3			2	3	2	2	3
CO4		2			2	2	3	2	3

Unit 1:

Learning Objectives:

1. To develop the knowledge on thermodynamics
2. To understand the heat conduction
3. To understand the heat transfer

Fundamentals of Thermodynamics and Heat Transfer: Basics of thermodynamics upto second law – Laws of Thermodynamics – Heat engines, refrigerators and heat pumps; thermodynamic cycles-power and refrigeration cycles; Laws of heat transfer – Thermal resistance network – Heat conduction equation – Critical radius of insulation – Initial and Boundary conditions; Non-dimensional Numbers in heat transfer; Heat transfer from extended surfaces; Heat Exchangers: Types and applications – Overall heat transfer coefficient – LMTD and NTU methods.

Unit 2:
Learning Objectives:

1. To develop the knowledge on solar radiation and its measurement.
2. To develop the knowledge on heat collector
3. To understand the heat exchanger

Solar radiation measurement instruments – Pyranometer&Pyrheliometer; Solar Thermal Collectors – Liquid Flat plate collector construction and analysis – Thermal resistance network model – Heat transfer correlations – performance characteristics and factors affecting – Concentrating type collectors – Construction and working – Tracking mechanisms – Heliostats with central receiver –Solar Process Loads – Collector Heat Exchanger Factor, Collector Arrays - Series Connections, Series Arrays with Sections Having Different Orientations.

Unit 3:

Learning Objectives:

1. To develop the knowledge on solar thermal collector and solar thermal power generation
2. To develop the knowledge on performance analysis of solar thermal collector
3. To develop the knowledge on different application of solar thermal collector
4. To develop the skill on solar thermal collector design

Solar thermal applications – Solar water heaters – Space heating – Active and passive heating – Solar air heaters – Solar chimney; Solar thermal power plants – Low, medium and high temperature systems – Performance analysis; Solar Ponds – Convective and non-convective ponds – Salt gradient solar pond – Experimental studies; Water desalination using solar still; Space cooling and refrigeration

TEXT BOOKS/ REFERENCES:

1. John A. Duffie and W. A. Beckman, "Solar Engineering of Thermal Processes", John Wiley and Sons, 2013.
2. F.P. Incopera and D.P. Dewitt, "Fundamentals of Heat Transfer", John Wiley and Sons, 2011. 3. John Twidell and Tony Weir, "Renewable Energy Resources", SecondEdition, Taylor and Francis, 2005.
4. Y. A. Cengel& M. A. Boles, "Thermodynamics – an engineering approach," Eighth Edition, McGraw Hill

education, 2016.

5. Y. A. Cengel& A. J. Ghajar, “Heat and Mass Transfer,” Fifth Edition, McGraw Hill education, 2016

Evaluation Pattern:

Assessment	**Internal**	**End Semester**
Periodical 1 (P1)	15	
Periodical 2 (P2)	15	
*Continuous Assessment (CA)	20	
End Semester		50

*CA - Can be quizzes, assignments, projects, and reports.