MSc ENERGY SCIENCE

Curriculum and Syllabus

DEPARTMENT OF SCIENCES

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COIMBATORE, TAMILNADU – 641112

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Curriculum and Syllabus – 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	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**

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 enable students 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 (6thEd.)
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 (2nd 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.

Justification for CO-PO Mapping:

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is using mathematics to represent a physical problem and once framed properly, using mathematical tools to solve the problem. It develops analytical skills to formulate a problem precisely by effectively breaking down a complex problem into simpler steps. Hence, it is given an affinity of 2.	2
CO2-PO1	CO2 is also related to using mathematical tools of curve fitting to analyze physical problems, which agrees with the PO1 viz., formulate and analyze complex mechanisms. Hence, it is also given an affinity of 2. Moreover, this CO2 helps to identify problems by plotting such as extrapolation and interpolation.	2
CO4-PO1	As CO4 is related to using optimization tools for solving problems, it helps in mathematically framing a problem as a minimization/optimization problem. In this, students will take case studies and frame problem as a mathematical optimization problem and solve it using the techniques taught. Hence, it has an affinity level of 1 with PO1.	1
CO3-PO3	CO3 is related to using statistical tools for inferences about a hypothesis problem. This helps in effective scientific communication and is closely related to PO3. Hence it is given an affinity level of 2.	2
CO4-PSO1	CO4 involves learning and using optimization techniques to solve a mathematical problem. In real case studies, this is equivalent to situations such as energy optimization in a process to obtain the most optimum conditions of operation. The PSO1 is also related to using scientific fundamentals with a focus on enhancing knowledge of energy sciences. Using optimization techniques is part of studying energy engineering. Hence an affinity level of 2 is given.	2

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, color centers, 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 anti ferromagnetism 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.

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to describing the crystal structure, defects and diffraction. CO1improves the fundamentals of crystal physics in students. Since PO1 is related to gaining knowledge on basic science fundamentals, CO1 has been mapped with PO1 with maximum affinity of 3.	3
CO1-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development. CO1 is related to crystal physics which is necessary to address the scientific problems related to the materials used in sustainable development. The aaffinity level between CO1 and PO2 can be 2 and not the maximum as much complex problems will not be dealt in CO1.	2

CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. It is essential to gain the knowledge on the concepts of crystal physics as presented in CO1, to understand the technological developments in the energy production etc. The CO1 mapping with PSO1 is given an affinity of 2 as it will not fully contribute to PSO1	2
CO2-PO1	CO2 is related to understand phonon dispersion in lattice and electrical conductivity of metals which requires the application of basic science. Since PO1 is related to using the basic sciences, CO2 is given maximum affinity of 3 when mapped with PO1.	3
CO2-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. CO2 is all about the thermal and electrical conduction in metals development which is necessary in designing the solution for the scientific problems in sustainable development. Affinity level between CO2 and PO2 can be 2 and not the maximum as much complex problems will not be carried out in CO2.	2
CO2-PO6	As CO2 is about the thermal and electrical properties in metals it can't be avoided in the technological change in the modern developments needed for life-long learning as given in the PO6. The affinity level can be minimum of 1 while mapping CO2 with PO6, as it alone will not be sufficient in the addressing the need for independent life-long learning.	1
CO2-PSO1	Understanding of electrical andthermal conduction in solids (as in CO2) will require to be applied it in the energy production, conversion and utilization as given in PSO1. Hence, CO2 can be mapped with a medium affinity level of 2 with PSO1.	2
CO3-PO1	To understand the formation of electronic band structure and semiconductors as presented in CO3, the fundamental knowledge of basic science is required. Since PO1 is related to acquiring knowledge in basic sciences, CO3 has maximum affinity of 3 when mapped with PO1.	3
CO3-PO2	CO3 is related to understanding of different approaches for the formation of band structure and carrier dynamics in semiconductor.PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. As semiconductors will also play a major role in the needs of sustainable development, CO2 can be mapped with PO2 with a medium affinity of 2 not 3.	2
CO3-PO6	As CO3 is about the carrier dynamics in semiconductors, it is needed for the modern electronic and optoelectronic devices and the also for the technological change in the modern developments needed for life-long learning as given in the PO6. The affinity level can be minimum of 1 while mapping CO23 with PO6, as it alone will not be sufficient in the addressing the need for independent life-long learning.	1
CO3-PSO1	CO3 is related to energy band formation and semiconductors. PSO1 is related to solid understanding of the sciences and technology related to energy production, storage,	2

	conversion, utilization and conservation. The mapping of CO2 with PSO1 is given as 2 as the knowledge of semiconductors will be a part of the energy production, utilization etc.	
CO4-PO1	To understand the optical and dielectric properties as presented in CO3, the fundamental knowledge of basic science is required. Since PO1 is related to acquiring knowledge in basic sciences, CO4 has maximum affinity of 3 when mapped with PO1.	3
CO4-PO2	CO4 is related to understanding the optical and dielectric properties of solids. PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. Though the optical and dielectric materials will be needed in the material utilization of sustainable development, complex problems are not carried out in CO2 , so it can be mapped with PO2 with a medium affinity of 2 not 3.	2
CO4 - PSO1	Affinity level of CO4 with PSO1 is assigned a medium level of 2, as understanding the sciences of dielectric materials are necessary in addressing the energy production, storage and utilization etc. Affinity of higher level is not mapped since the CO4 will not completely contribute to the PSO1.	2
CO5-PO1	CO4 concerns with the different theories of magnetism and superconductors which require the basic knowledge of fundamental sciences. Since PO1 is related to knowledge of fundamental sciences, a maximum level of 3 is mapped for CO5-PO1	3
CO5-PO2	CO5 is related to the magnetic materials and superconductors. PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. As the magnetic and superconducting materials also play a major role in the needs of sustainable development, CO5 can be mapped with PO2 with a medium affinity of 2 not 3.	2
CO5-PSO1	Affinity level of CO5 with PSO1 is assigned a medium level of 2, as understanding the sciences of magnetic materials and superconducting materials are necessary in addressing the energy production, storage and utilization. Affinity of higher level is not mapped since the advanced technology is not dealt in CO5.	2

21PHY507	Electromagnetic Theory	3 1 0 4

Prerequisite: NIL

Course Objectives: To give an overview of foundations of electromagnetic theory starts from electrostatics, magneto statics 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, the fields 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; 4th Edition, (2015).
2. J. R. Reitz, F. J. Milford and R.W. Christy, Foundations of Electromagnetic Theory, 4th edition, Pearson Education India (2010).
3. P. Lorrain and D. Corson, Electromagnetic Fields and Waves, CBS Publishers and Distributors, 2nd 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, 3rd 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	-	-

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to understanding basic aspects of electrostatics and electric fields in matter. PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using first principles of basic sciences. Since student will be solving problems related to electrostatics, their analytical skills will be eventually improved. Hence the affinity level between CO1 and PO1 is given as 3 which is the maximum	3

CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is related to understanding basic aspects of electrostatics and electric fields in matter, the affinity level between CO1 and PO2 can be 2 and not the maximum. The basics of electrostatics is important to completely understand electromagnetic theory so that real time devices like wave guides can be designed in order to minimize electromagnetic energy/power loss. However, CO1 do not contribute to PO2 completely as only electrostatics knowledge in not sufficient to give solution to complex problems pertained to energy science. Hence the affinity level between CO1 and PO2 is not the maximum.	2
CO1-PO6	CO1 is related to understanding of electrostatics and Electric fields in matter and PO6 is related to students engaging in independent and lifelong learning. Hence, CO1-PO6 affinity level is 2 and not 3 or 1. This CO alone will not be sufficient to understand latest trend in energy science and hence the contribution of CO1 is not the maximum.	2
CO2-PO1	As CO2 is related to acquiring knowledge in magnetostatics, magnetic fields in matter and electrodynamics and PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is given as 3. Since students will be solving problems related to magnetostatics and electrodynamics, eventually their analytical skills will be improved and hence the affinity level between CO2 and PO1 is the maximum.	3
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO2 is related to understanding basic aspects of magnetostatics and magnetic field in matter, the affinity level between CO1 and PO2 can be 2 and not the maximum 3. The basics of magnetostatics is important to understand electromagnetic theory. As CO2 alone cannot contribute to designing solution of complex scientific problems, the affinity level with PO2 is 2 and not the maximum.	2
CO2-PO6	CO2 is related to understanding of magnetostatics and magnetic fields in matter and PO6 is related to students engaging in independent and lifelong learning. Hence, CO2-PO6 affinity level is 2 and not 3 or 1. This CO alone will not be sufficient to understand the latest trend in energy science and hence the contribution of CO1 to PO6 is not the maximum.	2
CO3-PO1	CO3 is related to analyzing propagation of electromagnetic waves in different media using Maxwell's equations andPO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum. The reason is due to the fact that students will be able to solve problems related to propagation of EM waves in different media which will enhance the analytical ability of students along with better understanding of the subject as a whole.	3
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 is related to analyzing	2

	the propagation of electromagnetic waves in different media the affinity level between CO3 and PO2 can be 2 and not the maximum 3. Electromagnetic waves and propagation of em waves are important to completely understand electromagnetic theory. As CO3 alone cannot contribute to designing solution of complex scientific problems related to energy science, the affinity level of CO3 with PO2 is 2 and not the maximum.	
CO3-PO6	CO3 is related to analyzing propagation of em waves in different media and PO6 is related to student's engagement in independent and lifelong learning of the subject related to energy science. Hence, CO2-PO6 affinity level is 2 and not 3 or 1. CO3 alone will not be sufficient to understand latest trends in energy science and hence the contribution of CO3 to PO6 is not the maximum.	2
CO4-PO1	As CO4 is related to understanding electromagnetic potentials and gauge transformations and PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is 3. Since students will be solving problems related to gauge transformations and potential formalism in electrodynamics, eventually their analytical skills will be improved and hence the affinity level between CO2 and PO1 is the maximum	3
CO4-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO4 is related to gauge transformations and potential formalism employed in electrodynamics, the affinity level between CO4 and PO2 can be 2 and not the maximum 3. Electromagnetic potentials and gauge transformations are important to understand electromagnetic theory as the theory of radiation can be completely explained in terms of em potentials. As CO4 alone cannot contribute to designing solution of complex scientific problems, the affinity level of CO4 with PO2 is 2 and not the maximum.	2
CO4-PO6	CO4 is related to understanding gauge transformations and potential formulation in electrodynamics and PO6 is related to student's engagement in independent and lifelong learning of the subject related to energy science. As CO4 alone will not be sufficient to understand latest trends in energy science, the affinity level between CO4-PO6 is 2 and not the maximum.	2
CO5-PO1	CO5 is related to acquiring knowledge in the theory of radiation and antenna fundamentals.PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is 3. Since students will be solving problems related to radiation and antennas, eventually their analytical skills will be improved and hence the affinity level between CO2 and PO1 is the maximum which is 3.	3
CO5-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO5 is related to acquiring knowledge on the theory of radiation and antenna fundamentals, the affinity level between CO5 and PO2 can be 2 and not the maximum 3. Radiation theory and working principles of antenna can give insight of applications of EM theory.	2

CO5-PO6	CO5 is related to acquiring knowledge on the theory of radiation and antenna fundamentals and PO6 is related to student's engagement in independent and lifelong learning of the subject related to energy science. As CO5 alone will not be sufficient to understand latest trends in energy science, the affinity level between CO1 and PO6 is given as 2 and the maximum.	2
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to understanding of electrostatics and contributes to PSO1 with an affinity level of 2. The electrostatics is important to understand electrodynamics which in turn is useful to understand em waves. Since the course deals with energy conversion also, knowledge about em wave interaction with material is important. Though CO1 does not fully contribute to PSO1, the affinity level between CO1 and PSO1 is given as 2.	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 deals with acquiring knowledge in magnetostatics and electrodynamics. In order to understand the interaction of em waves with matter, energy and power associated with em waves, knowledge of electrodynamics is important. This knowledge will be useful to understand the energy conversion phenomenon. Though CO2 does not completely contribute to PSO1, the affinity level between CO2 and PSO2 can be 2 instead of 3.	2
CO3-PSO1	CO3 is related to analysis of propagation of electromagnetic waves in different media. Knowledge of Maxwell's equations is important when EM waves to be guided without much loss through structures like wave guides. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 2.	2
CO4-PSO1	CO4 is related to understanding gauge transformations and potential formalism employed in electrodynamics. Maxwell's equation can be written in terms of scalar and vector potentials. Since em fields are described in terms of potentials and the knowledge enables one to device a structure in which the loss of em energy can be minimized and hence the em energy can be better utilized. Though CO4 cannot be completely mapped with PSO1, the affinity level is given 2 instead of 3.	2
CO5-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO5 is related to the understanding of radiation and antenna fundamentals. For receiving and transmitting em waves, knowledge of antenna and theory of radiation is paramount important. This knowledge is important for transmitting/receiving em energy without much loss with a suitable design of antenna structure which can result in better utilization of energy. Hence CO5 can be mapped with PSO1 with an affinity level of 2 instead of 3 or 1.	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, Eigen values 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 Eigen values, 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	-	-

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to understanding basic aspects of quantum postulates. PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using first principles of basic sciences. Since student will be solving problems related postulates of quantum mechanics, their analytical skills will be eventually improved. Hence the affinity level between CO1 and PO1 is given as 3 which is the maximum	3

CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is related to understanding basic aspects of quantum postulates, the affinity level between CO1 and PO2 can be 2 and not the maximum. The basics of postulates of quantum mechanics are indeed important to understand quantum mechanics so that real time semiconductor based energy devices can be designed. Hence the affinity level between CO1 and PO2 is not the maximum.	2
CO2-PO1	As CO2 is related to acquiring knowledge in solving one dimensional problems, PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is given as 3. Since students will be solve problems related to Schrodinger's equation and eventually their analytical skills will be improved and hence the affinity level between CO2 and PO1 is the maximum.	3
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO2 is related to understanding basic aspects of applying Schrodinger's equation, the affinity level between CO1 and PO2.	2
CO3-PO1	CO3 is related to analyzing one of the significant angular momentum of quantum systems and PO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum. The reason is due to the fact that students will be able to solve problems related to angular momentum operators which will enhance the analytical ability of students along with better understanding of the subject as a whole.	3
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 is related to analyzing the angular momentum in quantum mechanics the affinity level between CO3 and PO2 can be 2 and not the maximum 3.	2
CO4-PO1	As CO4 is related to understanding Fermi Dirac and Bose Einstein Statistics and PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is 3. Since students will be solving problems related to Fermi Dirac and Bose Einstein Statistics, eventually their analytical skills will be improved in and hence the affinity level between CO2 and PO1 is the maximum	3
CO4-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO4 is related to Fermi Dirac and Bose Einstein Statistics, the affinity level between CO4 and PO2 can be 2 and not the maximum 3.	2
CO5-PO1	CO5 is related to acquiring knowledge in the theory of FD statistics to get Fermi energy, PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is 3. Since students will be solving problems related to FD statistics, eventually their	3

	analytical skills will be improved and hence the affinity level between CO2 and PO1 is the maximum which is 3.	
CO5-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO5 is related to acquiring knowledge on the theory of FD statistics to get Fermi energy, the affinity level between CO5 and PO2 can be 2 and not the maximum 3. FD statistics will give insight of applications on device development on energy harvesting.	2
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to understanding of quantum postulates which contributes to PSO1 with an affinity level of 2.	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 deals with acquiring knowledge in usage of Schrodinger's equation to quantify the parameters related to energy applications. In order to understand the semiconductor related energy device the knowledge of usage of Schrodinger's equation is important.	2
CO3-PSO1	CO3 is related to quantifying angular momentum and usage of angular momentum operators, it is essential to understand spin related aspect of energy application. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 2.	2
CO4-PSO1	CO4 is related to understanding the fundamental theories in Fermi Dirac and Bose Einstein Statistics and their applications. Though CO4 cannot be completely mapped with PSO1, the affinity level is given as 2 instead of 3.	2
CO5-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO5 is related to the understanding of FD statistics to get Fermi energy and hence CO5 can be mapped with PSO1 with an affinity level of 2 instead of 3 or 1.	2

21PHY586	Energy Science Laboratory	0 0 4 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 for analyzing capacitance, charge transfer resistance and Warburg impedance of 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 conversion which 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

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is mapped to PO1 with an affinity level of 3, since it is related to performing and analyzing results obtained from Hall experiments. To analyze results it is required to have science knowledge and problem analysis skill.	3
CO1-PO2	As PO2 is related to science knowledge and complex problem analysis and CO1 is about performing a set of Hall experiments and analyzing results, CO1 is mapped to PO2 with an affinity level of 2.	2
CO1-PO3	CO1 is about performing a set of Hall experiments and analyzing results and PO3 is related to communication, reports preparation and presentation. In this context, CO1 is mapped with PO3 with an affinity level of 3.	3
CO1-PO5	Since PO5 includes working in a team and doing experiments with interdisciplinary nature and CO1 is about performing a set of Hall experiments and analyzing results, it is mapped to PO5 with an affinity level of 2.	2
CO2-PO1	CO2 imparts knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures and PO1 is related to science knowledge and problem analysis, the affinity level can be 3.	3
CO2-PO2	PO2 is related to science knowledge and complex problem analysis and CO2 imparts knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures, CO2 is mapped with PO2 with an affinity level of 2.	2
CO2-PO3	Since CO2 imparts the basic knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures and PO3 is related to communication, reports preparation and presentation, CO2 is mapped with PO3 with an affinity level of 3.	3
CO2-PO5	PO5 includes working in a team and doing experiments with interdisciplinary nature and CO2 imparts knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures, it is mapped to PO5 with an affinity level of 2.	2
CO3-PO1	CO3 is related to electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance of dielectrics and PO1 is related to science knowledge and problem analysis, the affinity level can be 3.	3
CO3-PO2	As CO3 imparts knowledge on electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance of dielectrics. In this context, CO3 is mapped to PO2 with an affinity level of 2.	2
CO3-PO3	PO3 is related to communication, reports preparation and presentation, and CO3 is related to electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance of dielectrics, CO3 is mapped to PO3 with an affinity level of3.	3
CO3-PO5	CO3 is related to electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance eof dielectrics and PO5 includes working in a team and doing experiments with interdisciplinary nature, the affinity level can be 2.	2

CO4-PO1	CO4 is related to performing energy related experiments and analyze the results and present; hence mapped with PO1 with an affinity level of 3.	3
CO4-PO2	PO2 is related to science knowledge and complex problem analysis and CO4 is related to performing energy related experiments and analyze the results and present. Hence, CO4 with PO2 with an affinity level of 2.	2
CO4-PO3	CO4 is related to performing energy related experiments and analyze results and present and PO3 is related to communication, reports preparation and presentation. Hence, CO4 with PO2 with an affinity level of 3.	3
CO4-PO5	Since PO5 includes working in a team and doing experiments with interdisciplinary nature, and CO4 is related to performing energy related experiments and analyze the results and present, the affinity level can be 2.	2
CO1-PSO1	PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation. Since CO1 is about performing a set of Hall experiments and analyzing results, mapped with PSO1 with an affinity level of 2.	2
CO1-PSO3	CO1 is about performing a set of Hall experiments and analyzing results. PSO3 is related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 2.	2
CO2-PSO1	Since PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation and CO2 imparts the basic knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures, it is mapped with PSO1 with an affinity level of 2.	2
CO2-PSO3	CO2 conveys the basic knowledge on UV-Vis. spectroscopy and analyzing optical properties of nanostructures. PSO3 is related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 2.	3
CO3-PSO1	PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation and CO3 is related to electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance of dielectrics. Hence, provides the basic science required for analyzing the properties of the materials. In this context, CO3 is mapped with PSO1 with an affinity level of 3.	3
CO3-PSO3	CO3 is related to electrochemical impedance spectroscopy for analyzing capacitance, charge transfer resistance and Warburg impedance of dielectrics and PSO3 is related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 2	2
CO4-PSO1	CO4 is related to performing energy related experiments and analyze results and present and PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation. Hence mapped with PSO1 with an affinity level of 3.	3
CO4-PSO3	PSO3 is related to shifting from fossil fuels to renewable sources and CO4 is related to performing energy related experiments and analyze results and present. Hence mapped with PSO1 with an affinity level of 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.

Justification for CO-PO Mapping:

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is mapped with PO1 with an affinity level of 3, since it is related to understand various types of materials used in the energy applications. To understand they have to analyze the different properties of the materials	3
CO2-PO1	CO2 imparts basic knowledge on the electrical and optical properties of the energy related materials, it also imparts analytical skill on predict the structure properties relationship of the materials, this context, CO2is mapped with PO1 with an affinity level of 3.	3
CO2-PO2	Since CO2 imparts the basic knowledge on the electrical and optical properties of the energy related materials it is mapped with PO2 with an affinity level of 3.	3
CO3-PO1	CO3 imparts basic understand of the fundamental principles behind the individual characterization methods, analyze, interpret and present observations from the different characterization methods. Hence mapped with PO1 with an affinity level of 3.	3
CO3-PO2	As CO3 imparts knowledge on the fundamental principles behind the individual characterization methods, analyze, interpret and present observations from the different	3

	characterization methods. In this context, CO3 is mapped with PO2 with an affinity level o 3.	
CO4-PO1	CO4 imparts fundamental knowledge on various nanostructured materials and their energy related applications; hence mapped with PO1 with an affinity level of 3.	3
CO4-PO2	CO4corresponds to the understanding of different types of nanostructured materials and their application in different avenue of energy technology. Hence, CO4 with PO2 with an affinity level of 3.	3
CO1-PSO1	PSO1 corresponds to solid understanding of sciences. Since CO1 relates to the basic knowledge of understand various types of materials used in the energy applications, mapped with PSO1 with an affinity level of 2.	2
CO2-PSO1	CO2 imparts basic knowledge on the electrical and optical properties of the energy related materials. Hence, provides solid understanding of the sciences and technology related to materials science. In this regard, CO2 is mapped with PSO1 with an affinity level of 3.	3
CO3-PSO1	CO3 corresponds to the fundamental principles behind the individual characterization methods, analyze, interpret and present observations from the different characterization methods. Hence, provides the basic science required for analyzing the properties of the materials. In this context, CO3 is mapped with PSO1 with an affinity level of 2.	2
CO4-PSO1	CO4 imparts knowledge on different types of nanostructured materials and their application in different avenue of energy technology. Hence mapped with PSO1 with an affinity level of 3.	3

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 Sweep Voltammetry 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, Lead Acid Batteries, Nickel-Metal Hydride batteries, Silver peroxide zinc battery, Lithium-Ion Batteries and Lithium polymer batteries, Sodium batteries, Thin-film Batteries, Redox flow batteries, Metal Air Batteries, Reserve batteries, Energy Storage for Fuel Cells; Hydrogen storage- Hydrogen Economy, Different modes of hydrogen 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

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 deals with all fundamental aspects quantitative electrochemistry and ionics	3
CO1-PO2	CO1 cover the analytical skills to design the quantity of electrochemical reactions and making the decisions on the electrolytes to be used for a specific purpose	2
CO1-PO3	Thorough knowledge on electrochemistry will help them to design and present about the subject	2

CO1-PSO1	Fundamentals of electrochemistry learned will be useful in exploring opportunities in energy sector	3
CO1-PSO2	Selection of cost-effective electrolytes and the electrode materials will be discussed in this	2
CO2-PO1	Fundamental aspects of thermodynamics of electrochemistry is discussed here	3
CO2-PO2	Will be able to understand, apply, analyze experimental data and designing solutions	2
CO2-PO3	Will be in a position to comprehensively communicate about the feasibility of reactions	2
CO2-PSO1	The fundamentals of electrode materials and its need and selection will be discussed	3
CO2-PSO2	Thorough knowledge on the thermodynamics of electrode processes will help in the selection of efficient electrode materials suitable for various industries	2
CO3-PO1	Fundamental concepts electroanalytical techniques are discussed here	3
CO3-PO2	Design the experiments based on the characterization and testing of electrode and electrolyte required for various industries	3
CO3-PO3	Research based knowledge on electroanalytical techniques will be discussed here and will help the students to communicate effectively regarding the electrochemical reactions	2
CO3-PSO1	Students will have good grasp on the need of electroanalytical techniques in characterization and testing of electrochemical systems	2
CO3-PSO2	Applied level electrochemical knowledge helps the students to get design cost effective characterization and testing procedures based on electroanalytical techniques	2
CO4-PO1	All fundamentals of the electrochemical processes, their design and the electrochemical energy storage devices will be discussed here	3
CO4-PO2	Analytical skills will be provided for understanding the electrochemistry to design storage devices and processes	2
CO4-PO3	Sound knowledge on the working principle and design help the students to think and write about the development of new storage devices and processes	2
CO4-PSO1	All the fundamentals on the working and design of energy storage devices and processes are covered here	2
CO4-PSO2	Design of cost-effective power sources and processes will be discussed	2
CO4-PSO3	Fundamentals on the working of all batteries and processes will allow the development of green energy storage devices and processes	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 & Accessories Coal & Ash Handling Systems Condensers 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.

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to understand the Physics and technology of thermal power generation. It develops analytical skills to develop the knowledge on thermal power generation. Hence, it is given an affinity of 2.	2
CO2-PO1	CO2 is also related to acquire knowledge on nuclear physics and correlates the knowledge to nuclear power generation. Hence, it is also given an affinity of 2.	2
CO3-PO1	As CO3 is Development of knowledge on combustion process and application of combustion process on energy generation. Hence, it has an affinity level of 2 with PO1.	2
CO1-PO2	PO2 deals procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development CO1 covers the basic science and technology of thermal power generation so affinity level 3 can made.	3
CO2-PO2	CO2 ie related with knowledge on nuclear physics and correlates the knowledge to nuclear power generation, PO2 deals procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development. So nuclear power have a major role for sustainable development so maximum affinity can mapped between them.	3
CO3-PO2	CO3 deals with the knowledge on combustion process and application of combustion process on energy generation. As energy is essential for sustainable development so the affinity level can mapped with a value of 3.	3
CO1-PO3	CO1is understood the Physics and technology of thermal power generation. This helps in effective scientific communication and is closely related to PO3. Hence it is given an affinity level of 2.	2

CO2-PO3	PO3 is related with the effective Communication on complex scientific activities and CO2 develops the knowledge on nuclear power generation. This helps in effective scientific communication and the affinity level between CO2 and PO3 can mapped as 2.	2
CO3-PO3	CO3 is related with the knowledge on combustion process and application of combustion process on energy generation. This helps in effective scientific communication and is closely related to PO3. Hence it is given an affinity level of 2	2
CO1-PO6	CO1 is related to understand the Physics and technology of thermal power generation and PO6 is related with the life-long learning in the broadest context of technological change. So the affinity level between CO1 and PO6 can mapped with maximum affinity of 3	3
CO2-PO6	PO6 is related with the life-long learning in the broadest context of technological change and CO2 develops the knowledge on nuclear power generation. So the affinity level between CO2 and PO6 can mapped with maximum affinity of 3	3
CO3-PO6	CO3 is related with the knowledge on combustion process and application of combustion process on energy generation. PO6 is related with the life-long learning in the broadest context of technological change. So the affinity level between CO23and PO6 can mapped with maximum affinity of 3	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 develops the knowledge on thermal power generation so the affinity level may be 3	3
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 develops the knowledge on nuclear power generation so the affinity level can mapped with a value of 3.	3
CO3-PSO1	CO3 develops the knowledge on by combustion of fossil fuels. PSO1 is related to solid understanding of the sciences and technology related to energy production, So the affinity level can be fixed at 3.	3
CO1-PSO2	PSO2 is related with economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO1 develops the knowledge on thermal power generation which is a pillar for sustainable development. So the affinity level can mapped between PSO2 and CO1 as 2.	2
CO2-PSO2	CO2 develops the knowledge on nuclear power generation and PSO2 is related with economic, environmental and policy impact of a sustainable energy practice for a sustainable society. So the affinity between them can mapped as 2 as nuclear power is needed for sustainable development.	2
CO3-PSO2	PSO2 is related with economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO3 is related with the knowledge on combustion process and application of combustion process on energy generation. So the affinity level can mapped between PSO2 and CO1 as 2.	2

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, international protocols for energy and environment, governing and nodal national/international agencies and their role. Import and export position, Resources, Reserves, Indian Energy Scenario, Energy Security - Concept, Trade-Off between Energy Security and 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 between energy 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 issues associated 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 environment regarding energy conservation and energy auditing.

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

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.

Justification for CO-PO Mapping:

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is related to understanding the present energy demand and energy production in world and India, PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. So the correlation of energy demand and energy production and formulate the future prediction will come for both CO1 and PO1. Hence the affinity level between CO1 and PO1 is given as 3 which is the maximum	3
CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is developing the knowledge on present energy demand and energy production in world and India level between CO1 and PO2 can be 3. As the knowledge on energy demand and production will educate the student about the specific need for sustainable development	3
CO2-PO1	As CO2 developed the conceptual knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing, PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is given as 3. Analytical skill will help the student to correlate the technology and the economics.	3
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental	2

	considerations resulting in sustainable development and CO2 is related to knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing, the affinity level between CO2 and PO2 should be 2.	
CO3-PO1	CO3 is ability to analyze the viability of energy conservation projects and PO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum. The reason is due to the fact that students will be able to analyze strategically the necessity of the energy conservation.	3
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 is related to analyze the viability of energy conservation projects, the affinity level between CO3 and PO2 can be 2 and not the maximum 3.	2
CO4-PO1	As CO4 is related to Capability to integrate various options and assess the business and policy environment regarding energy conservation and energy auditing, the affinity level between CO4 and PO1 is 3. Since to fulfill the CO4 we need the strong analytical skill which will be developed by PO1.	3
CO4-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO4 is related to assess the business and policy environment regarding energy conservation and energy auditing, the affinity level between CO4 and PO2 can be 3.	3
CO5-PO1	CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing, PO1 is related to developing analytical skills, the affinity level between CO5 and PO1 is 3. Since students will be able to developed strategic plane and policy for energy conservation and audit, eventually their analytical skills will be improved and hence the affinity level between CO5 and PO1 is the maximum which is 3.	3
CO5-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing, the affinity level between CO5 and PO2 can be 2 and not the maximum 3.	2
CO1-PO3	Since PO3 is related to effective communication on complex scientific activities and CO1 is developing the knowledge on present energy demand and energy production in world and India level between CO1 and PO3 can be 3. As the knowledge on energy demand and production will educate the student and generate the communication skill.	3
CO2-PO3	CO2 is related with the knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing and PO3 is related to effective communication on complex scientific activities. So the affinity between them can fixed at 3.	3

CO4-PO3	CO4 is related to assess the business and policy on environment regarding energy conservation and energy auditing, which will directly related with communication skill so the affinity level between CO4 and PO5 is the maximum which is 3.	3
CO5-PO3	PO3 is related to effective communication on complex scientific activities and CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing, the affinity level between CO5 and PO3 can be mapped with the value of 3.	3
CO2-PO5	PO5 is related with 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 and CO2 is related with the knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing. So both of them can be mapped with maximum affinity of 3.	3
CO3-PO5	CO3 is related to analyze the viability of energy conservation projects and PO5 is related to manage the project for team work so the affinity of 3 is possible for them	3
CO4-PO5	CO4 is related to assess the business and policy on environment regarding energy conservation and energy auditing and PO5 is related with 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. So the affinity level between them can map as 3.	3
CO5-PO5	CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing which is directly related with the PO5. So the affinity between them can fixed at 3.	3
CO2-PO6	PO6 is related with life-long learning in the broadest context of technological change and CO2 deals with knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing. SO the affinity between them can mapped as 3.	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to understanding the present energy demand and energy production in world and India which contributes to PSO1 with an affinity level of 2.	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 deals with knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing. So CO2 can be mapped with PSO1 with an affinity level of 2.	2
CO3-PSO1	CO3 is ability to analyze the viability of energy conservation projects. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 2.	2
CO4-PSO1	CO4 is related to capability to integrate various options and assess the business and policy environment regarding energy conservation and energy auditing, Though CO4 cannot be completely mapped with PSO1, the affinity level is given as 2 instead of 3.	2

CO5-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing and hence CO5 can be mapped with PSO1 with an affinity level of 2 instead of 3 or 1.	2
CO1-PSO2	PSO2 is related with understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO1 is related to understanding the present energy demand and energy production in world and India which is directly related for sustainable development so the affinity between them can mapped with a value of 3.	3
CO2-PSO2	CO2 deals with knowledge of the technology, economics and regulation related issues associated with energy conservation and energy auditing and PSO2 is related with understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. So the affinity between CO2 and PSO2 can mapped with a value of 3.	3
CO4-PSO2	CO4 is related to capability to integrate various options and assess the business and policy environment regarding energy conservation and energy auditing, Though CO4 cannot be completely mapped with PSO2, the affinity level is given as 2 instead of 3	2
CO5-PSO2	PSO2 is related with understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO5 is related to advocacy of strategic and policy recommendations on energy conservation and energy auditing. Which will help for sustainable development so the affinity level can mapped with a value of 3.	3
CO1-PSO3	PSO3 is related to basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources. CO1 is related to understanding the present energy demand and energy production in world and India which contributes to the renewable energy system, So the affinity level 2 can mapped between them.	2

21PHY587	Project Based Laboratory	0 0 4 2

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 present the findings.

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	-	-

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is mapped to PO1 with an affinity level of 3, since it is related to performing experiment on materials fabrication and properties and device fabrication for energy application, which needs science knowledge and problem analysis skill.	3
CO1-PO2	As PO2 is related to science knowledge and complex problem analysis and CO1 is about performing a set of experiments and analyzing results, CO1 is mapped to PO2 with an affinity level of 3.	3
CO1-PO3	CO1 is about performing a set of experiments and analyzing results and PO3 is related to communication, reports preparation and presentation. In this context, CO1 is mapped with PO3 with an affinity level of 3.	3
CO1-PO5	Since PO5 includes working in a team and doing experiments with interdisciplinary nature and CO1 is about performing a set of experiments from materials fabrication to device application and analyzing results, it is mapped to PO5 with an affinity level of 3.	3
CO1-PO6	CO1 is related with the knowledge of materials fabrication and properties and device fabrication for energy application. PO6 develops the ability to engage in independent and life-long learning in the broadest context of technological change. So the affinity between them should be maximum.	3
CO2-PO1	CO2 correlates the knowledge on science of solids, electrochemistry with experimental results and PO1 is related to science knowledge and problem analysis, the affinity level can be 3.	3
CO2-PO2	PO2 is related to science knowledge and complex problem analysis and CO2 related to the knowledge on science of solids, electrochemistry and correlates them with experimental results, CO2 is mapped with PO2 with an affinity level of 3.	3
CO2-PO3	CO2 imparts the basic knowledge on science of solids, electrochemistry and analyzing experimental results. PO3 is related to communication, reports preparation and presentation, CO2 is mapped with PO3 with an affinity level of 3.	3
CO2-PO5	PO5 includes working in a team and doing experiments with interdisciplinary nature and CO2 imparts knowledge science of solids, electrochemistry and correlates them with experimental results, it is mapped to PO5 with an affinity level of 2.	2
CO2-PO6	PO6 related to the ability to engage in independent and life-long learning in the broadest context of technological change and CO2 correlates the basic knowledge to experimental results which is closely related to the PO6. So the affinity level mapped with a value of 3.	3
CO3-PO1	CO3 is related hands on experience on energy harvesting and energy storage device fabrication and PO1 is related to science knowledge and problem analysis which is basic perquisite for CO3, the affinity level can be 2.	2
CO3-PO2	As CO3 imparts hands on experience on energy harvesting and energy storage device fabrication. PO2 is related to science knowledge and complex problem analysis In this context, CO3 is mapped to PO2 with an affinity level of2.	2

CO3-PO3	PO3 is related to communication, reports preparation and presentation, and CO3 is related to hands on experience on energy harvesting and energy storage device fabrication, CO3 is mapped to PO3 with an affinity level of3.	3
CO3-PO4	Lab safety and ethics on reporting the experimental results is main component for fabrication of energy harvesting and energy storage device so the affinity level between CO3 and PO4 can mapped as 2.	2
CO3-PO5	CO3 is related to hands on experience on energy harvesting and energy storage device fabrication and PO5 includes working in a team and doing experiments with interdisciplinary nature, the affinity level can be 3.	3
CO3- PO6	PO6 related to the ability to engage in independent and life-long learning in the broadest context of technological change and CO3 is related to hands on experience on energy harvesting and energy storage device. These two are closely related, so the affinity level mapped with a value of 3	3
CO4-PO1	As CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally present the findings, the affinity level between CO4 and PO1 is 3. Since to fulfill the PO1 we need the strong analytical skill which will be developed by CO4.	3
CO4-PO3	Since PO3 is related to communication and documentation and CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally the present findings, the affinity level between CO4 and PO3 can be 3.	3
CO4-PO4	PO4 related to the ethical principles and professional ethics and responsibilities and norms of scientific practice. CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally present the findings. So the affinity level between Co4 and PO4 can mapped with a value of 3.	3
CO4-PO5	Since PO5 related to the demonstration 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, and CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally present the findings, the affinity level can be 3.	3
CO4-PO6	PO6 related to the ability to engage in independent and life-long learning in the broadest context of technological change and CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally present the findings. These two are closely related, so the affinity level mapped with a value of 2.	2
CO1-PSO1	PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation. Since CO1 is about knowledge of materials fabrication and properties and device fabrication for energy application, this can be mapped with PSO1 with an affinity level of 2.	2
CO1-PSO2	CO1 is related to knowledge of materials fabrication and properties and device fabrication for energy application and PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, the affinity level between CO1 and PSO2 can be 3	3
CO1-PSO3	CO1 is about performing a set of experiments and analyzing results on materials fabrication and properties and device fabrication for energy application. PSO3 is	3

	related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 3.	
CO2-PSO1	Since PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation and CO2 correlates the basic knowledge to experimental results, it is mapped with PSO1 with an affinity level of 2.	2
CO2-PSO3	CO2 related to the knowledge on science of solids, electrochemistry and correlates them with experimental results. PSO3 is related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 3.	3
CO3-PSO1	PSO1 corresponds to understanding of sciences related to energy production, storage, conversion, utilization and conservation and CO3 is related to hands on experience on energy harvesting and energy storage device fabrication. Hence, provides the basic science required for analyzing the properties of the materials. In this context, CO3 is mapped with PSO1 with an affinity level of 3.	3
CO3-PSO2	PSO2 related with the understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, which is supported by energy harvesting and energy storage devices. So the affinity level between CO3 and PSO2 has mapped with 3.	3
CO3-PSO3	CO3 is related to hands on experience on energy harvesting and energy storage device fabrication and PSO3 is related to shifting from fossil fuels to renewable sources. The experiments may help in identifying suitable ways for the shift. Hence the affinity level can be 3	3
CO4-PSO1	CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally present the findings and PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization Though CO4 cannot be completely mapped with PSO1; the affinity level is given as 2 instead of 3	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 based on 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.

Justification for CO-PO Mapping

Mapping	Justification	Affinity level
CO1-PO1	CO1 deals with all understanding of the basic science of solar cell and PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. So the affinity may be fixed at 3.	3
CO1-PO2	PO2deals procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable developmentCO1 covers the basic science behind the working of solar PV so affinity level 3 can made.	3
CO1-PO3	PO3 deals with effective communication of complex scientific activities and CO1 develop the basic understanding of solar PV which will help the effective communication, so the affinity level may not be high and can make it 2.	2
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to understanding the solar energy production so CO1 can map with PSO1 with an affinity level of 2	2
CO1-PSO2	PSO2 develops the understanding of the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. It can be mapped with the science of solar energy generation with the affinity level of 2.	2
CO1-PSO3	CO1 deals with the understanding of the basic science of solar cell, since PSO3 is related to basic to advanced aspects of Renewable Energy systems, CO1 has been mapped with PSO3 with maximum affinity of 3	3
CO2-PO1	CO2 helps to calculate the solar radiation at a given location, time and tilt. Compare the methods of synthesis and characterization of different solar cells and the PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. So the affinity may be fixed at 3	3
CO2-PO2	Will be able to understand, apply, solar PV generation for sustainable development	2
CO2-PO3	The knowledge of solar radiation and solar cell fabrication will help the effective communication of complex scientific activities.	2
CO2-PSO1	Understanding the Solar radiation and solar PV fabrication for CO2 will help to understand the energy production needed for PSO1.	3
CO2-PSO2	The knowledge of solar radiation and solar PV fabrication will developed the sustainable energy practice.	3
CO2-PSO3	PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources, CO2 is for the knowledge of solar radiation and solar PV fabrication. This is very closely related with PSO3.	3
CO3-PO1	CO3 deals with the design of simple photovoltaic systems which will help to developed analytical skill.	3
CO3-PO2	CO3 deals with the design of simple photovoltaic systems which will help to developed sustainable energy production.	2
CO3-PO3	The design of simple photovoltaic systems will help the students to communicate effectively regarding the solar energy generation.	2
CO3-PSO1	Students will have good grasp on the need of solar PV for renewable energy generation.	2

CO3-PSO2	Fabrication of simple photovoltaic systems will developed the sustainable energy practice	2
CO3-PSO3	PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources and CO3 deals with the design of simple photovoltaic systems, which is a main component of renewable energy system. So CO3 has been mapped with PSO3 with maximum affinity of 3.	3
CO4-PO1	Mainly solar thermal devices and systems are related to CO4, which will help to developing analytical skills needed for PO1. So CO4 has been mapped with PO1 with maximum affinity of 3	3
CO4-PO2	Analytical skills will be provided for understanding the solar thermal and energy storage devices.	2
CO4-PO3	Sound knowledge on the working principle and design help the students to think and write about the development of solar thermal devices	2
CO4-PSO1	All the fundamentals on the working and design of solar thermal devices will provided here.	2
CO4-PSO2	Design of cost-effective solar thermal heater will be discussed for sustainable energy practice	2
CO4-PSO3	PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources and CO4 deals with the solar thermal devices and systems, which is one of the main component of renewable energy system. So CO4 has been mapped with PSO3 with maximum affinity of 3	3
CO5-PO1	CO5 deals with the understanding of the basic science of recent trend in solar PV and solar thermal technology. PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. So the affinity may be fixed at 3	3
CO5-PO2	PO2 deals procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development CO5covers the basic science of recent trend in solar PV and solar thermal technology. So affinity level 2 can made.	2
CO5-PO3	PO3 deals with effective communication of complex scientific activities and CO5 develop the basic understanding of recent trend in solar PV and solar thermal technology, which will help the effective communication, so the affinity level may not be high and can make it 2	2
CO5-PSO1	PSO1 related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservationCO5covers the recent trend in solar PV and solar thermal, which is directly related with the energy generation so the maximum affinity can mapped between them.	3
CO5-PSO2	CO5 develop the basic understanding of recent trend in solar PV and solar thermal technology and PSO2 related to understanding of the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. So CO5 helps for sustainable practice and we can map them with affinity level of 2.	2
CO5-PSO3	PSO3 deals with basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources and CO5 deals with recent trend in solar PV and solar thermal technology. Both of them are directly related and maximum affinity level mapped between them.	3

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.
Justification for CO-PO Mapping

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is related to exploring the science of energy extraction from biomass and water. CO1improves the fundamentals of science of energy generation. Since PO1 is related to gaining knowledge on basic science fundamentals, CO1 has been mapped with PO1 with maximum affinity of 3.	3
CO1-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental	3

	considerations resulting in sustainable development. CO1 is related to science of energy extraction from biomass and water. So the affinity level between CO1 and PO2 can mapped with maximum affinity of 3.	
CO1-PO6	CO1 is related to exploring the science of energy extraction from biomass and water, and PO6 is related with the life-long learning in the broadest context of technological change. So the affinity level between CO1 and PO6 can mapped with maximum affinity of 3	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1, helps to understand the energy production from biomass. The CO1 can map with PSO1with maximum affinity of 3.	3
CO1-PSO2	CO1 is related to exploring the science of energy extraction from biomass and water Since PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, CO1 has been mapped with PSO2 with maximum affinity of 3.	3
CO1-PSO3	PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources. As CO1 is exploring the science of energy extraction from biomass and water so the maximum affinity is possible between CO1 and PSO3.	3
CO2-PO1	Familiarity with various biomass conversion processes was developed in CO2 and PO1 is to develop the basic science fundamentals so the affinity mapping can be 3.	3
CO2-PO2	PO2 is related to designing solutions for complex scientific problems for sustainable development and CO2 develop the knowledge on the different biomass conversion process so these two can be mapped with 3 affinity level.	3
CO2-PO6	CO2 is related to various biomass conversion processes, and PO6 is related with the life-long learning in the broadest context of technological change. So the affinity level between CO2 and PO6 can mapped with a value of 2	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2, helps to understand the various biomass conversion processes. The CO2 can mapped with PSO1 with maximum affinity of 3	3
CO2-PSO2	CO2 is related to gaining knowledge on various biomass conversion processes. Since PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, CO2 has been mapped with PSO2 with maximum affinity of 3.	3
CO2-PSO3	CO2 is related to gaining knowledge on various biomass conversion processes Since PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources, CO2 has been mapped with PSO2 with maximum affinity of 3	3
CO3-PO1	CO3 deals with design of bio and hydro power generation systems. So the mapping with PO1 to develop the basic science fundamentals may be 2	2
CO3-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental	3

	considerations resulting in sustainable development. CO3 is related to design of bio and hydro power generation systems. The affinity level between CO3 and PO2 can mapped with maximum affinity of 3	
CO3-PO6	CO3 is related to the knowledge on design of bio and hydro power generation systems.and PO6 is related with the life-long learning in the broadest context of technological change. So the knowledge on design of bio and hydro power generation can help on lifelong learning process. The affinity level between CO3 and PO6 can mapped with a value of 2	2
CO3-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO3, helps to understand the design of bio and hydro power generation systems. The CO3 can mapped with PSO1 with maximum affinity of 3	3
CO3-PSO2	CO3 is related to design of bio and hydro power generation systems, PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO3 has been mapped with PSO2 with maximum affinity of 3.	3
CO3-PSO3	PSO3 is for learning the basic to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources. As CO3 is related to the knowledge on design of bio and hydro power generation systems so the maximum affinity is possible between CO1 and PSO3	3
CO4-PO1	PO1 is related to gaining knowledge on basic science fundamentals and CO4 is the understanding of wind resources, principles of conversion and technologies, which improves the basic knowledge for energy harvesting so CO4 has been mapped with PO1 with maximum affinity of 3	3
CO4-PO2	CO4 is related to the understanding of wind resources, principles of conversion and technologies and PO2 is for designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development. So aaffinity level between CO4 and PO2 can mapped with maximum affinity of 3.	3
CO4-PO6	PO6 is 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 and CO4 is the understanding of wind resources, principles of conversion and technologies, which improves the basic knowledge for energy harvesting which will help for lifelong learning, so CO4 has been mapped with PO6 with maximum affinity of 2	2
CO4-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO4, helps to understand the wind energy generation. The CO3 can mapped with PSO1 with maximum affinity of 3	3
CO4-PSO2	CO4 is related to gaining knowledge on wind energy generation. Since PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, CO4 has been mapped with PSO2 with maximum affinity of 3	3

CO4-PSO3	CO4 is related to gaining knowledge on wind energy generation and PSO3 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, CO2 has been mapped with PSO2 with maximum affinity of 3	3

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.

Justification for CO-PO Mapping:

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is related to understanding the fundamentals of machine learning and AI, PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. As the machine learning is a tool for analytical skill, hence the affinity level between CO1 and PO1 is given as 3 which is the maximum	3
CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is related to understanding the the fundamentals of machine learning and AI. So the affinity level between CO1 and PO2 can be 2. As the knowledge on machine learning will educate the student more energy efficient.	2
CO2-PO1	As CO2 is related with various methods of machine learning, PO1 is related to developing analytical skills, the affinity level between CO2 and PO1 is given as 2.	2
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO2 is related to various methods of machine learning, the affinity level between CO2 and PO2 should be 2.	2
CO3-PO1	CO3 is deals with energy efficiency and Smart grid management by machine learning and PO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum. The reason is due to the fact that students	3

	will be able to analyze energy demand and energy production to manage the smart grid.	
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 is related to energy efficiency and Smart grid management by machine learning, the affinity level between CO3 and PO2 should be 3.	3
CO3-PO3	As CO3 is deals with energy efficiency and Smart grid management by machine learning, the affinity level between CO4 and PO3 is 2. Since the smart grid management should be reported nicely this will enhance the communication skill.	2
CO3-PO5	PO5 demonstrate the knowledge and understanding of scientific and management principles and apply these to one's own work for interdisciplinary team which will related nicely with the CO3, which is related with energy efficiency and Smart grid management by machine learning. So the affinity level of 3 can map with CO3 and PO5.	3
CO3-PO6	PO6 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, which is closely related to CO3which deals with energy efficiency and Smart grid management by machine learning. So the maximum affinity 3 has mapped with CO3 and PO6	3
CO4-PO1	As CO4 is related to understanding of the renewable energy forecasting by machine learning, the affinity level between CO4 and PO1 is 3. Since to fulfill the PO1 we need the strong analytical skill which will be developed by CO4.	3
CO4-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO4 is related to understanding of the renewable energy forecasting by machine learning, the affinity level between CO4 and PO2 can be 3.	3
CO4-PO3	As CO4 is related to understanding of the renewable energy forecasting by machine learning, the affinity level between CO4 and PO3 is 2. Since the renewable energy forecasting should be reported nicely which will enhance the communication skill as related with PO3.	2
CO4-PO5	PO5 demonstrate the knowledge and understanding of scientific and management principles and apply these to one's own work for interdisciplinary team which will related nicely with the CO4 for forecasting the renewable energy by machine learning. So the affinity level of 2 was mapped for CO4 and PO5.	2
CO4-PO6	PO6 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, which is very ideal for CO4 as it is related to understanding of the renewable energy forecasting by machine learning. So the maximum affinity 3 has mapped with CO4 and PO6.	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related	2

	to understanding the fundamentals of machine learning and AI which contributes to PSO1 with an affinity level of 2.	
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 deals with various methods of machine learning. So CO2 can be mapped with PSO1 with an affinity level of 2.	2
CO3-PSO1	CO3 is related to energy efficiency and Smart grid management by machine learning. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 3.	3
CO3-PSO2	PSO2 is related with the understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO3 deals with energy efficiency and Smart grid management by machine learning. So CO3 is closely related with the sustainable practice and can be mapped with PSO2 with an affinity level of 3	3
CO3-PSO3	CO3 is related to energy efficiency and Smart grid management by machine learning. Since PSO3related with the basic learning to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources. As the grid management is necessary for renewable energy system so CO3 can be mapped with PSO3 with an affinity level of 2	2
CO4-PSO1	CO4 is related to understanding of the renewable energy forecasting by machine learning and PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization Though CO4 cannot be completely mapped with PSO1, the affinity level is given as 2 instead of 3.	2
CO4-PSO2	PSO2 is related with the understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society. CO3 deals with understanding of the renewable energy forecasting by machine learning. So CO4is ideally related with the sustainable practice and can be mapped with PSO2 with an affinity level of 3	3
CO4-PSO3	CO4 is related to understanding of the renewable energy forecasting by machine learning. Since PSO3related with the basic learning to advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources. As the renewable energy forecasting is necessary for renewable energy system so CO3 can be mapped with PSO3 with an affinity level of 3	3

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		

Justification forCO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to identifying a research topic in Energy Science, PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. As the identification of research topic is related to analytical skill, hence the affinity level between CO1 and PO1 is given as 3 which is the maximum.	3
CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is related to understanding the identifying research topic for mini project. So the affinity level between CO1 and PO2 can be 2. As the knowledge on energy science will guide the students for choosing the area of research.	2
CO2-PO1	As CO2 is related to systematic literature review, identify gaps, PO1 is related to developing analytical skills which needs a detailed literature review, the affinity level between CO2 and PO1 is given as 3.	3
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO2 is	3

	related to literature review, identification of gaps and define objectives, the affinity level between CO2 and PO2 should be 3.	
CO2-PO3	CO2 is related to systematic literature review, identify gaps, PO3 is related to communication and documentation, the affinity level between CO2 and PO3 is given as 2.	2
CO2-PO5	Since PO5 is related to project management and finance and CO2 is related to systematic literature review, identify gaps, the affinity level between CO2 and PO5 is given as 2.	2
CO2-PO6	CO2 is related to systematic literature review, identify gaps, PO 6 is related to Life-long learning, the affinity level between CO2 and PO6 is given as 2.	
CO3-PO1	CO3 deals with developing methodology for prototype/model/experimental setup and PO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum.	3
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 deals with developing methodology for prototype/model/experimental setup, the affinity level between CO3 and PO2 should be 3.	3
CO3-PO3	CO3 deals with developing methodology for prototype/model/experimental setup andPO3 is related to communication and documentation, the affinity level between CO3 and PO3 is given as 2.	2
CO3-PO4	Since PO4 is related to ethical principles and commit to professional ethics and responsibilities and norms of scientific practice and CO3 deals with developing methodology for prototype/model/experimental setup, the affinity level between CO3 and PO4 should be 3.	3
CO3-PO5	CO3 deals with developing methodology for prototype/model/experimental setup and PO5 is related to project management and finance, the affinity level between CO3 and PO5 should be 3.	3
CO3-PO6	As PO 6 is related to Life-long learning and CO3 deals with developing methodology for prototype/model/experimental setup, the affinity level between CO3 and PO6 should be 2	2
CO4-PO1	As CO4 is related to documentation and presentation, the affinity level between CO4 and PO1 is 3. Since to fulfill the PO1 we need the strong analytical skill which will be developed by CO4.	3
CO4-PO3	Since PO3 is related to communication and documentation and CO4 is related to documentation and presentation, the affinity level between CO4 and PO3 can be 3.	3
CO4-PO4	CO4 is related to documentation and presentation and PO4 is related to ethical principles and commit to professional ethics and responsibilities and norms of scientific practice, the affinity level between CO4 and PO4 can be 3	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to understanding the identifying research topic for mini project which contributes to PSO1 with an affinity level of 2.	2

CO1-PSO2	CO1 is related to understanding the identifying research topic for project and PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, the affinity level between CO4 and PSO2 can be 2.	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 is related to systematic literature review, identifying gaps. So CO2 can be mapped with PSO1 with an affinity level of 3.	3
CO2-PSO2	CO2 is related to systematic literature review, identifying gaps and PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, the affinity level between CO2 and PSO2 can be 2.	2
CO2-PSO3	As PSO3 is related to learning advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources and CO2 is related to systematic literature review, identifying gaps, the affinity level between CO2 and PSO3 can be 2.	2
CO3-PSO1	CO3 deals with developing methodology for prototype/model/experimental setup. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 3.	3
CO3-PSO2	As PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, and CO3 deals with developing methodology for prototype/model/experimental setup, the affinity level between CO3 and PSO2 should be 3.	3
CO3-PSO3	CO3 deals with developing methodology for prototype/model/experimental setup. PSO3 is related to learning advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources, the affinity level between CO3 and PSO2 should be 2.	2
CO4-PSO1	CO4 is related to documentation and presentation and PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization Though CO4 cannot be completely mapped with PSO1; the affinity level is given as 2 instead of 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		

Justification forCO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to identifying a research topic defining the objective and scope of work, PO1 is related to developing analytical skills to identify, formulate, and analyze complex mechanisms using principles of basic sciences. As the identification of research topic is related to analytical skill, hence the affinity level between CO1 and PO1 is given as 3 which is the maximum.	3
CO1-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO1 is related to identifying a research topic defining the objective and scope of work. So	3

	the affinity level between CO1 and PO2 can be 2. As the knowledge on energy science will guide the students for choosing the area of research.	
CO2-PO1	As CO2 is related to developing methodology for conducting the theoretical/experimental study, PO1 is related to developing analytical skills which need suitable methodology, the affinity level between CO2 and PO1 is given as 3.	3
CO2-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO2 is related to developing methodology for conducting the theoretical/experimental study, the affinity level between CO2 and PO2 should be 3.	3
CO2-PO3	CO2 is related to developing methodology for conducting the theoretical/experimental study; the affinity level between CO2 and PO3 is given as 2.	2
CO2-PO5	Since PO5 is related to project management and finance and CO2 is related to developing methodology for conducting the theoretical/experimental study, the affinity level between CO2 and PO5 is given as 2.	2
CO2-PO6	CO2 is related to developing methodology for conducting the theoretical/experimental study, PO 6 is related to Life-long learning, the affinity level between CO2 and PO6 is given as 2.	
CO3-PO1	CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment and PO1 is related to improving analytical skills of students, CO3-PO1 affinity level is 3 which is the maximum.	3
CO3-PO2	Since PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development and CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment, the affinity level between CO3 and PO2 should be 3.	3
CO3-PO3	CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment andPO3 is related to communication and documentation, the affinity level between CO3 and PO3 is given as 2.	2
CO3-PO4	Since PO4 is related to ethical principles and commit to professional ethics and responsibilities and norms of scientific practice and CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment, the affinity level between CO3 and PO4 should be 3.	3
CO3-PO5	CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment and PO5 is related to project management and finance, the affinity level between CO3 and PO5 should be 3.	3

CO3-PO6	As PO 6 is related to Life-long learning and CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment, the affinity level between CO3 and PO6 should be 2	2
CO4-PO1	As CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally the present findings, the affinity level between CO4 and PO1 is 3. Since to fulfill the PO1 we need the strong analytical skill which will be developed by CO4.	3
CO4-PO3	Since PO3 is related to communication and documentation and CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally the present findings, the affinity level between CO4 and PO3 can be 3.	3
CO4-PO4	CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally the present findings and PO4 is related to ethical principles and commit to professional ethics and responsibilities and norms of scientific practice, the affinity level between CO4 and PO4 can be 3	3
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO1 is related to identifying a research topic defining the objective and scope of work which contributes to PSO1 with an affinity level of 2.	2
CO1-PSO2	CO1 is related to identifying a research topic defining the objective and scope of work and PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, the affinity level between CO4 and PSO2 can be 2.	2
CO2-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation. CO2 is related to developing methodology for conducting the theoretical/experimental study. So CO2 can be mapped with PSO1 with an affinity level of 3.	3
CO2-PSO2	CO2 is related to developing methodology for conducting the theoretical/experimental study and PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, the affinity level between CO2 and PSO2 can be 2.	2
CO2-PSO3	As PSO3 is related to learning advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources and CO2 is related to developing methodology for conducting the theoretical/experimental study, the affinity level between CO2 and PSO3 can be 2.	2
CO3-PSO1	CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment. Since PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization, CO3 can be mapped with PSO1 with an affinity level of 3.	3
CO3-PSO2	As PSO2 is related to understanding the economic, environmental and policy impact of a sustainable energy practice for a sustainable society, and CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment, the affinity level between CO3 and PSO2 should be 3.	3

CO3-PSO3	CO3 deals with planning, managing and executing experimental work to obtain results with a concern for safety, industry and environment. PSO3 is related to learning advanced aspects of Renewable Energy systems completely prepared to shift from fossil fuels to renewable sources, the affinity level between CO3 and PSO2 should be 2.	2
CO4-PSO1	CO4 is related to organizing, analyzing results and draw conclusions, document technical report and orally the present findings and PSO1 is related to solid understanding of sciences and technologies related to energy production, conversion and utilization Though CO4 cannot be completely mapped with PSO1; the affinity level is given as 2 instead of 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 of various nanostructures 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.

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO 1 is related to applying concepts of solid state physics to understand difference between nano and bulk materials. Students gain knowledge on properties of nanostructures and synthesis procedures. Hence the affinity level is 3. CO 1 is mapped with PO 1 which is related to gaining scientific knowledge by the students after completion of the degree.	3
CO2-PO1	Since PO 1 is related to scientific knowledge gained by the students and CO 2 is related to understanding various properties of nanostructures pertaining to energy applications, the affinity level between CO 2 and PO 1 is mentioned as 3.	3
CO3-PO1	CO 3 is related to understanding of various nanostructured materials and after careful analysis and choose them for energy related applications. Since PO1 is related to scientific knowledge gained by the students in physics after completion of the degree, CO 3-PO 1 affinity level is 3 and not 2 or 1.	3
CO4-PO1	CO 4 is related to applying knowledge to describe working of solar energy conversion and energy storage devices. Since PO 1 is gaining scientific knowledge, the affinity level between them is 3.	3
CO1-PO2	Selection of nanostructures for energy related applications considering health, safety and environmental issues. This requires knowledge for selection of relevant materials to develop suitable solutions. Since PO 2 is related to designing solutions for complex scientific problems CO 1 has maximum affinity 3 when mapped with PO 2.	3
CO2-PO2	CO 2 is related to understanding of quantum and phonon confinements. These concepts are required for developing solutions for energy conversion problems using nanostructures by taking into account of safety and health issues. Since PO 2 is related to designing solutions for complex scientific problems, CO 2 has maximum affinity to PO 2 and hence given an affinity level of 2.	2
CO3-PO2	CO 3 is related to understanding of various nanostructured materials and after careful analysis choose them for energy related applications by taking into account of safety and health issues. As PO1 is related to designing solutions for complex scientific problems, CO 3 has maximum affinity of 3 with PO 2.	3
CO4-PO2	CO 4 is related to applying knowledge to describe working of solar energy conversion and energy storage devices. Since PO2 is related to designing solutions for complex scientific problems and maximum affinity level of 3 is given for CO 4-PO 2 mapping.	3
CO4-PO3	CO 4 is related to applying knowledge toexplain the working of solar energy conversion devices, and energy storage devices. Since PO 3 is related to effective communication of scientific activities with science community, the affinity level of 2 is given.	2
CO4-PO6	CO 4 is related to applying knowledge toexplain the working of solar energy conversion devices, and energy storage devices. With basic understanding of these concepts students will be able to update and understand recent developments and	3

	technology changes. PO 6 is related to independent and life-long learning, affinity level of 3 is given.	
CO1-PSO1	CO 1 is related to applying concepts of solid state physics to understand difference between nano and bulk materials. Students gain knowledge on properties of nanostructures and synthesis procedures. As PSO 1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation, affinity level 3 is given	3
CO2-PSO1	CO 2 is related to understanding of quantum and phonon confinements and concept of excitons in nanostructures. Since PSO 1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation, affinity level 3 is given.	3
CO3-PSO1	CO 3 is related to understanding of various nanostructured materials and after careful analysis and choose them for energy related applications. PSO 1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation, affinity level 2 is given.	2
CO4-PSO1	CO 4 is related to applying knowledge toexplain the working of solar energy conversion devices, and energy storage devices. PSO 1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization and conservation, affinity level 2 is given.	2
CO4-PSO3	CO 4 is related to applying knowledge toexplain the working of solar energy conversion devices, and energy storage devices. PSO 3 is related to advanced aspects of renewable energy systems, affinity level 3 is given.	3

21PHY562	Physics of Nuclear Energy	3 0 0 3

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	-	-

Justification for CO-PO Mapping:

Mapping	**Justification**	**Affinity level**
CO1-PO1	CO1 is mapped with PO1 with an affinity level of 3, since it is related to fundamental knowledge acquired on atomic and nuclear physics to understand nuclear reactors and their operation. Besides, it also imparts the necessary analytical skill to understand the atomic and nuclear properties.	3
CO2-PO1	CO2 imparts basic knowledge on sustained neutron chain reaction, different types of nuclear reactors and reactor components. Besides, it also imparts analytical skill on calculation of Neutron Flux and Fluence; and Neutron capture cross section of a medium/material. In this context, CO2is mapped with PO1 with an affinity level of 3.	3

CO2-PO2	Since CO2 imparts the basic knowledge on design of different type of nuclear reactors and materials selection criteria for reactor components it is mapped with PO2 with an affinity level of 3.	3
CO3-PO1	CO3 imparts basic knowledge on radiation damage and their influence on properties of non-fuel reactor materials. Hence mapped with PO1 with an affinity level of 3.	3
CO3-PO2	As CO3 imparts knowledge on radiation-induced damage on reactor components and hence provides solution for design of nuclear reactors to control the damage. In this context, CO3 is mapped with PO2 with an affinity level o 3.	3
CO4-PO1	CO4 imparts fundamental knowledge on different types of metallic and ceramic fuels, their fabrication technique and properties; hence mapped with PO1 with an affinity level of 3.	3
CO4-PO2	CO4corresponds to the understanding of different types of metallic and ceramic fuels, their fabrication technique and properties, essential factors while designing the nuclear reactor. Hence, CO4 with PO2 with an affinity level of 3.	3
CO5-PO1	CO5 provides the basic knowledge on biological effects of radiation and benefits; principles of reactor safety; radiation hazards and protection; and handling of nuclear wastes. Hence, mapped with PO1 with an affinity level of 3.	3
CO5-PO2	Since CO4 imparts knowledge on biological effects of radiation and benefits; principles of reactor safety; radiation hazards and protection; and handling of nuclear wastes, which are important factors while designing the reactors considering health, and safety of the environment for sustainable development. Hence, mapped with PO2 with an affinity level of 3.	3
CO1-PSO1	PSO1 corresponds to solid understanding of sciences. Since CO1 relates to the basic knowledge of science of atomic and nuclear physics to understand nuclear reactors, mapped with PSO1 with an affinity level of 1.	1
CO2-PSO1	CO2 imparts basic knowledge on sustained neutron chain reaction, different types of reactors and reactor components. Hence, provides solid understanding of the sciences and technology related to nuclear energy production. In this regard, CO2 is mapped with PSO1 with an affinity level of 3.	3
CO3-PSO1	CO3 corresponds to the understanding of the radiation damage and their influence on properties of non-fuel reactor materials. Hence, provides the basic science required for analyzing the radiation induced damage to account the safety of the nuclear reactor, its operation and lifespan. In this context, CO3 is mapped with PSO1 with an affinity level of 3.	3
CO4-PSO1	CO4 imparts knowledge on different types of metallic and ceramic fuels, their fabrication technique and properties. Hence mapped with PSO1 with an affinity level of 3.	3
CO5-PSO1	CO5 imparts knowledge on biological effects of radiation and benefits; principles of reactor safety; radiation hazards and protection; and handling of nuclear wastes. Hence, mapped with PSO1 with an affinity level of 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 course also introduces 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-voltage characteristics 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.

Justification for CO-PO Mapping:

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to describing the crystal structure and growth of semiconducting materials. CO1improves the fundamentals of crystal physics in students. Since PO1 is related to gaining knowledge on basic science fundamentals, CO1 has been mapped with PO1 with maximum affinity of 3.	3
CO1-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs considering health, safety and environmental considerations resulting in sustainable development. CO1 is related to crystal physics which is necessary to address the scientific problems related to the materials used in sustainable development. Affinity level between CO1 and PO2 can be 2 and not the maximum as much complex problems will not be dealt in CO1.	2
CO1-PSO1	PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization, and conservation. It is essential to gain the knowledge on the concepts of growth of semiconductor materials as presented in CO1 which will lead to the technological developments in the energy production etc. The CO1 mapping with PSO1 is given as high affinity of 3	3
CO1-PSO2	Growth of semiconductors in CO1 will a play role in deciding the environmental impact on the sustainable society, so it is given a medium affinity of 2 when matched with PSO2.	2

CO2-PO1	CO2 is related to understand the energy bands of semiconductors and the carrier dynamics which require the application of basic science. Since PO1 is related to using the basic sciences, CO2 is given maximum affinity of 3 when mapped with PO1.	3
CO2-PO2	PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. CO2 is understanding the tuning of bandgap of the semiconductors for different optoelectronic applications. Affinity level between CO2 and PO2 can be 2 and not the maximum as much complex problems will not be carried out in CO2.	2
CO2-PSO1	Knowledge on the carrier dynamics in semiconductors as in CO2 will be essential in designing the devices related to the energy production, conversion and utilization as given in PSO1. Hence, CO2 can be mapped with a high affinity level of 3 with PSO1.	3
CO3-PO1	To acquire the knowledge on the formation of p-n junctions and the luminescence of semiconductors are presented in CO3, the fundamental knowledge of basic science is required. Since PO1 is related to acquiring knowledge in basic sciences, CO3 has maximum affinity of 3 when mapped with PO1.	3
CO3-PO2	CO3 is related to formation of p-n junctions and the luminescence of semiconductors. PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. As luminescence in semiconductors and diodes will also play a major role in the needs of sustainable development, CO2 can be mapped with PO2 with a medium affinity of 2 not 3 as integrated devices are not part off.	2
CO3-PSO1	CO3 is related to homo and hetero-junction formations. PSO1 is related to solid understanding of the sciences and technology related to energy production, storage, conversion, utilization, and conservation. The mapping of CO3 with PSO1 is given as 3 as the knowledge of semiconductor junctions will be a part of the technology required in energy production and utilizations.	3

CO4-PO1	CO4 is all about understanding the working of optoelectronic devices for which the fundamental knowledge of basic science is essential. Since PO1 is related to acquiring knowledge in basic sciences, CO4 has maximum affinity of 3 when mapped with PO1.	3
CO4-PO2	CO4 is related to understanding the optoelectronic devices. PO2 is related to designing solutions for complex scientific problems and evolve procedures that meet specified needs in sustainable development. Though the optoelectronic devices will be needed in the sustainable development, complex problems are not carried out in CO2 , so it can be mapped with PO2 with a medium affinity of 2 not 3.	2
CO4-PO6	As CO4 is about the operating principles of modern optoelectronic devices which will be needed for the life-long learning as given in the PO6. The affinity level can be medium of 2 while mapping CO4 with PO6, as it alone will not be sufficient in the addressing the need for independent life-long learning.	2
CO4 - PSO1	Affinity level of CO4 with PSO1 is assigned a maximum level of 3, as understanding the working of optoelectronic devices will be necessary in addressing the energy production, storage and utilization etc.	3
CO4-PSO2	Usage of optoelectronic devices as in CO4 will a play role in deciding the environmental impact on the sustainable society, so it is given a high affinity of 3 when matched with PSO2.	3
CO4-PSO3	PSO3 is related to the basic to advanced aspects of renewable energy systems where the usage of optoelectronic devices can't be ignored as in CO4. Hence the mapping of CO4 with PSO3 is given a maximum affinity of 3.	3

21PHY564	THIN FILM TECHNOLOGY	3 0 0 3

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 electron bombardment 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 and transmittance 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 magnetic films - 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

CO-PO-PSO justification

Mapping	Justification	Affinity level
CO1-PO1	CO1 is related to understanding the principle, differences and similarities, advantages and disadvantages of different thin film deposition methods it require the basic knowledge regarding the differences between the thin and thick film and the basic knowledge regarding the deposition so it is related to PO1	1
CO1-PO2	As CO1 is related to the basic understanding regarding the differences between thick and thin film and the parameters adjusted to get a uniform thickness thin film, it requires the analyzing capacity of the students to go for a suitable method of preparation and so it is related to PO2.	2
CO2-PO1	CO2 is related to evaluation and use of models for understanding nucleation and growth of thin films it requires the basic knowledge of various nucleation theories and so it is related toPO1	1
CO2-PO2	As CO@ is the understanding and evaluation of different nucleation models for the growth of the thin films it requires the analyzing skills of the students regarding the nucleation theories and ti find the radius of the nuclei and hence draw conclusions and hence it is related to PO2.	2
CO3-PO1	CO3 is related to analyzing the thin film properties for various applications the students should know the basic knowledge in selecting	1

	the suitable material with properties foe suitable applications, so it is related to PO1.	
CO3-PO2	The application of thin films depends on the thin film properties; students should analyze the material properties for suitable applications soCO3 is related to PO2.	2
CO3-PO3	Application of thin films are based on the material properties students should know the proper selection of the material for suitable applications with appropriate consideration for the public health and safety and environmental considerations. So CO3 is related to PO3.	2
CO3-PO4	The analysis of thin film properties to apply for various applications includes the use of research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions. So CO3 is related to PO4.	2
CO4-PO1	To improve problems solving skills related to evaluation of different properties of thin films it requires basic knowledge regarding the physics of thin films. So CO4 it is related PO1.	1
CO4-PO2	To improve different properties of thin films students should be able to identify and analyze the problems so that they can formulate the synthesis process. So CO4 is related to PO2.	2
CO4-PO3	To improve the knowledge in the evaluation of different properties of thin films one should be able to design solutions for complex chemical process problems and evolve procedures that meet the specified needs with appropriate consideration for the public health and safety and environmental considerations. So CO4 is related to PO3.	2
CO4-PO4	The problem-solving skills in tuning and improving the properties of thin films require the use of research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions. So CO4 is related to PO4.	2
CO1-PSO3	To understand the principle, differences and similarities, advantages and disadvantages of different thin film deposition methods. After gaining the knowledge Students will acquire experimental skills which enable them to take precise measurements in labs and analyze the measurements to draw valid conclusions. In addition, students will exhibit skills in solving problems using computer programming, plotting tools, and related software. SoCO1 is related to PO3	2
CO2-PSO3	By understanding nucleation theories Students will acquire skills which enable them to analyze it to draw valid conclusions. In addition, students	2

	will exhibit skills in solving problems using computer programming, plotting tools, and related software	
CO3-PSO3	After getting the knowledge to analyze thin film properties to apply for various applications Students will acquire experimental skills which enable them to take precise measurements and analyze the measurements to draw valid conclusions. In addition, students will exhibit skills in solving problems using computer programming, plotting tools, and related software	2
CO4-PSO3	After improving the problems solving skills in the of different properties of thin films students will acquire experimental skills in measurements and analyze the measurements to draw valid conclusions. In addition, students will exhibit skills in solving problems using computer programming, plotting tools, and related software.	2

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 2 Chemistry 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 3 Green 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- Fluorous Biphase 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- Fluorous Biphase 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, Springer Briefs 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 the different 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.

Justification for CO-PO Mapping

Mapping	Justification	Affinity level
CO1-PO1	CO 1 is to attain the knowledge on different method of solar energy harvesting like solar thermal solar thermal power and solar PV. This improves student's knowledge in solar energy harvesting and hence the affinity level is 3-the maximum instead of 2 or 1 when CO1 is mapped with PO1 which is related to gaining scientific knowledge by the students after completion of the degree	3
CO1-PO2	Since PO2 is related to problem analysis and CO1 is related to different method of solar energy harvesting in present energy crisis, the affinity level between CO1 and PO2 is mentioned as 3.	2
CO1-PO6	:As PO6 deals with 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. The affinity level of 2 was mapped with CO1 and PO6.	2
CO1-PSO1	CO1 is related to different method of solar energy harvesting like solar thermal solar thermal power and solar PV, which will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 3	3
CO1-PSO2	As PSO2 deals with the understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society and Co1 is related to different method of solar energy harvesting like solar thermal solar thermal power and solar PV so the affinity level of 3 is given for CO1 and PSO2.	3
CO1–PSO3	CO1 is to attain the knowledge on different method of solar energy harvesting like solar thermal solar thermal power and solar PV and this will be helpful for advancement renewable	3

	Energy systems so maximum affinity can mapped with CO1 and PSO3.	
CO2-PO1	CO2 is related to working principle of solar PV, Physics behind photo current and photo voltage generation in solar cell. Since PO1 is related to analytical skills to identify, formulate, and analyze complex mechanisms, CO2-PO1 affinity level is 3.	3
CO2-PO2	As CO2 is related to understanding and analyzing the solar cell performance from the physics behind it and PO2 is related to developing solutions for environmental needs, the affinity level between them is 2.	2
CO2-PO6	As CO2 is related to understanding and analyzing the solar cell performance it will be help full for life-long learning in the broadest context of technological change so the affinity level of CO2 and PO6 can fixed as 2.	2
CO2-PSO1	As CO2 is related to understanding and analyzing the solar cell performance, which will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 3	3
CO2–PSO3	CO2 develop the understanding and analyzing the solar cell performance and this will be helpful for advancement renewable Energy systems so maximum affinity can mapped with CO2 and PSO3.	3
CO3-PO1	Fabrication of different types of solar cell and methods to enhance the efficiency of solar cell is the main focus of CO3. Since PO1 is related to analytical skills to identify, formulate, and analyze complex mechanisms, CO3 has maximum affinity 3 when mapped with PO1.	3
CO3-PO2	CO3 is related to understanding solar cell fabrication and performance analysis. Since PO2 is related to improving analytical skills to identify, formulate, and analyze complex mechanisms, CO3 has maximum affinity to PO2 and hence given an affinity level of 3.	3
CO3-PO5	PO5 is related to Project management and finance, And fabrication of different types of solar cell and methods to	2

	enhance the efficiency of solar cell is the main focus of CO3. So CO3 has affinity level of 2 with PO5.	
CO3-PO6	PO6 is related to life-long learning in the broadest context of technological change. And fabrication of different types of solar cell and methods to enhance the efficiency of solar cell is the main focus of CO3. So CO3 has affinity level of 3 with PO6.	3
CO3-PSO1	CO3 is related to understanding solar cell fabrication and performance analysis, that is quite similar to the understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2	2
CO3–PSO3	CO3 develop the understanding solar cell fabrication and efficiency enhancement, and this will be helpful for advancement renewable Energy systems so maximum affinity can mapped with CO3 and PSO3.	3
CO4-PO1	CO4 is related gaining knowledge on recent trends and current research focus on the fabrication of solar cell and the PO1 is related to analytical skills to identify, formulate, and analyze complex mechanisms, CO4 has affinity of 1 with PO1.	1
CO4-PO2	CO4 is related to recent trends and current research focus on the fabrication of solar cell. Since PO2 is related to improving analytical skills to identify, formulate, and analyze complex mechanisms, so the affinity level of 2 is given for CO4-PO2 mapping.	2
CO4-PO6	PO6is related to life-long learning in the broadest context of technological change and CO4 is related gaining knowledge on recent trends and current research focus on the fabrication of solar cell. So the affinity can mapped with CO4 and PO6 as 2.	2
CO4-PSO1	CO4 is related to gaining knowledge on recent trends and current research focus on the fabrication of solar cell, that will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2	2

CO4-PSO2	As PSO2 deals with the understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society and CO4 is related to gaining knowledge on recent trends and current research focus on the fabrication of solar cell so the affinity level of 2 is given for CO4 and PSO2.	2
CO4-PSO3	Knowledge on recent trends and current research focus on the fabrication of solar cell will developed by CO4 and PSO3 deals with the basic to advanced aspects of Renewable Energy systems. So the affinity level between them fixed as 3.	3

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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.

Justification for CO-PO Mapping

Mapping	Justification	Affinity level
CO1-PO1	CO 1 is to understanding of the concepts of thermodynamics and heat transfer, PO1 is related to gaining scientific knowledge by the students after completion of the degree so the affinity level can fixed at 3.	3
CO1-PO6	As PO6 deals with 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. The affinity level of 2 was mapped with CO1 and	2

	PO6. As CO 1 develop the understanding of the concepts of thermodynamics and heat transfer.	
CO1-PSO1	CO1 is related to understanding of the concepts of thermodynamics and heat transfer, which will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2	2
CO1–PSO3	CO1 is to attain the knowledge on thermodynamics and heat transfer and this will be helpful for advancement renewable Energy systems so maximum affinity can mapped with CO1 and PSO3.	1
CO2-PO1	CO2 is related to application of principles of thermodynamics in energy transfer. Since PO1 is related to analytical skills to identify, formulate, and analyze complex mechanisms, CO2-PO1 affinity level is 3.	3
CO2-PO2	As CO2 is related to application of principles of thermodynamics in energy transfer and PO2 is related to developing solutions for environmental needs, the affinity level between them is 2.	2
CO2-PO6	As CO2 is related to ability to apply the principles of thermodynamics in energy transfer, it will be help full for life-long learning in the broadest context of technological change so the affinity level of CO2 and PO6 can fixed as 2.	2
CO2-PSO1	As CO2 is related to application of principles of thermodynamics in energy transfer, that will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2.	2
CO2–PSO3	CO2 develop the understanding and analyzing the energy transfer and this will be helpful for advancement renewable Energy systems so maximum affinity can mapped with CO2 and PSO3.	2
CO3-PO2	CO3 is related to analyze and evaluate heat transfer in buildings and heat exchangers. Since PO2 is related to improving analytical skills to identify, formulate, and	3

	analyze complex mechanisms, CO3 has maximum affinity to PO2 and hence given an affinity level of 3.	
CO3-PO5	PO5 is related to Project management and finance, and analysis and evaluation of heat transfer in buildings and heat exchangers is the main focus of CO3. So CO3 has affinity level of 2 with PO5.	2
CO3-PO6	PO6 is related to life-long learning in the broadest context of technological change. And analyze and evaluate heat transfer in buildings and heat exchangers is the main focus of CO3. So CO3 has affinity level of 3 with PO6.	3
CO3-PSO1	CO3 is related to analyze and evaluate heat transfer in buildings and heat exchangers, that is quite similar to the understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2	2
CO3-PSO2	CO3 is related to analyze and evaluate heat transfer in buildings and heat exchangers, that is helpful for to the understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society so the affinity to PSO2 is given as 2	2
CO3–PSO3	CO3 is related to analyze and evaluate heat transfer in buildings and heat exchangers, and this will be helpful for advancement renewable Energy systems so maximum affinity can mapped with CO3 and PSO3.	3
CO4-PO2	CO4 is related to solar thermal collector and its performance analysis. Since PO2 is related to improving analytical skills to identify, formulate, and analyze complex mechanisms, so the affinity level of 2 is given for CO4-PO2 mapping.	2
CO4-PO5	CO4 is related to solar thermal collector and its performance analysis. Since PO5 is related to Demonstrate knowledge and understanding of scientific and management principles and apply these to one’s own work, so the affinity level of 2 is given for CO4-PO5 mapping.	2
CO4-PO6	PO6 is related to life-long learning in the broadest context of technological change and CO4 is related principles of solar	2

	thermal collector and its performance analysis. So the affinity can mapped with CO4 and PO6 as 2.	
CO4-PSO1	CO4 is related to gaining knowledge on principles of solar thermal collector and its performance analysis, that will incorporated some understanding of the sciences and technology related to energy production, storage, conversion, utilization so the affinity to PSO1 is given as 2	3
CO4-PSO2	As PSO2 deals with the understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society and CO4 is related to gaining knowledge on solar thermal collector so the affinity level of 2 is given for CO4 and PSO2.	2
CO4-PSO3	Knowledge on solar thermal collector will be developed by CO4 and PSO3 deals with the basic to advanced aspects of Renewable Energy systems. So the affinity level between them fixed as 3.	3

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