Program Name: M.Sc. (Physics)

2 years Program following NEP Guidelines

Program Code: **PHY4201**

Offered by Department of Physics, School of Basic and Applied Sciences, Adamas University Duration: 2 Years

Academic Year: 2026-27

Course Structure

SCHOOL OF BASIC AND APPLIED SCIENCES

POSTGRADUATE COURSE STRUCTURE

M.Sc. (Physics) (2-year Program)

SEMESTER I

Sl. No.	Type of Course	Code	Title of the Course	Contact Hours Per Week				Remarks	NCRF Credit Level
				L	T	P	C		
1	CC	PHY451	Mathematical Methods	4	0	0	4		6.0
2	CC	PHY452	Classical Mechanics	4	0	0	4		6.0
3	CC	PHY453	Quantum Mechanics	4	0	0	4		6.0
4	DSE/MDE	PHY456/ PHY458/ PHY459/ PHY460/ PHY461	**Discipline Specific Elective courses-** 1. Quantum Information Theory and Quantum Computing 2. ASIC and FPGA design and applications 3. Analog and Digital Electronics 4. Electronics for renewable energy systems 5. Physics of Emerging Electronic Devices **SAWYAM MOOC courses** (Any courses aligning with the themes of specified DSE courses, subject to	4 /3 /4 /4 /4	0 /0 /0 /0 /0	0 /1 /0 /0 /0	4		6.0

			availability in the portal within the stipulated time frame) For example: ‘***Electronics and IoT design workshop***’ offered by Netaji Subhash University of Technology in the Swayam portal						
5	RM	MTH450	Research Methodology in Science	3	0	1	4		6.0
6	SEC (Hands-On Training)	PHY455	Physics Lab I	0	0	2	2		6.0
7	AEC		Foreign Language I	2	0	0	2		6.0
8	SEC		Career Development Course I (Soft Skill / Soft Skill and Aptitude Course	1	0	0	1		6.0
Semester Credits							25		

SEMESTER II									
Sl. No.	Type of Course	Code	Title of the Course	Contact Hours Per Week				Remarks	NCRF Credit Level
				L	T	P	C		
1	CC	PHY466	Classical Electrodynamics	4	0	0	4		6.0
2	CC	PHY467	Advanced Quantum Mechanics	4	0	0	4		6.0
3	CC	PHY468	Advanced Statistical Mechanics	4	0	0	4		6.0
4			**Discipline Specific Elective courses-**						6.0

	DSE	PHY456/ PHY458/ PHY459/ PHY460/ PHY461	1. Quantum Information Theory and Quantum Computing 2. ASIC and FPGA design and applications 3. Analog and Digital Electronics 4. Electronics for renewable energy systems 5. Physics of Emerging Electronic Devices **SAWYAM MOOC courses** (Any courses aligning with the themes of specified DSE courses, subject to availability in the portal within the stipulated time frame) For example: ‘***Electronics and IoT design workshop***’ offered by Netaji Subhash University of Technology in the Swayam portal	4 /3 /4 /4 /4	0 /0 /0 /0 /0	0 /1 /0 /0 /0	4		
5			**MDE Pool:**						6.0

	MDE	PHY470/ PHY471/ PHY472	1. AI Essentials – Concept and Applications 2. Numerical Techniques in Science 3. Unmasking Bio-signals **SAWYAM MOOC courses** (Any courses aligning with the themes of specified MDE courses, subject to availability in the portal within the stipulated time frame)	2 /1 /3	0 /0 /0	2 /3 /1	4		
6	AEC		Foreign Language II	2	0	0	2		6.0
7	SEC (Hands-On Training)	PHY469	Physics Lab II	0	0	2	2		6.0
8	SEC		Career Development Course I (Soft Skill / Soft Skill and Aptitude Course	1	0	0	1		6.0
Semester Credits							25		
Exit option with Post-Graduate Diploma after the first year or two semesters, with the completion of courses equivalent to 44 credits									

PG Curricular Structure with Coursework and Research

SEMESTER III									
Sl. No.	Type of Course	Code	Title of the Course	Contact Hours Per Week				Remarks	NCRF Credit Level
				L	T	P	C		
1	CC	PHY500	Atomic and Molecular	4	0	0	4		6.5

			Spectroscopy						
2	CC	PHY501	Solid State Physics	4	0	0	4		6.5
3	CC	PHY502	Advanced Physics Lab	0	0	2	2		6.5
4	DSE	PHY505/ PHY506/ PHY507/ PHY508/ PHY509/ PHY510	**Bucket List:** 1. Quantum Field Theory 2. Many-electron systems and Material Science 3. Biomedical Instrumentation and MEMS Technology 4. Astrophysics and Cosmology I 5. Statistical and Quantum Optics 6. Nanoscience and Nanomaterials	4	0	0	4		6.5
5	INT	PHY503	Internship	0	0	2	2		6.5
6		PHY504	Dissertation I	0	0	6	6		6.5
7	SEC		Career Development Course I (Soft Skill / Soft Skill and Aptitude Course	1	0	0	1		6.5
Semester Credits							23		

SEMESTER IV									
Sl. No.	Type of Course	Code	Title of the Course	Contact Hours Per Week				Remarks	NCRF Credit Level
				L	T	P	C		
1	CC	PHY511	Nuclear and Particle Physics	4	0	0	4		6.5
2	DSE	PHY514/ PHY515/ PHY516/ PHY517/ PHY518/ PHY519	**Bucket List:** 1. Particle Physics 2. Collective Phenomena in Solids 3. Imaging and Spectroscopy in Medical Diagnostics	4	0	0	4		6.5

			4. Astrophysics and Cosmology II 5. Optoelectronic Devices 6. Nanoelectronics and Nano-photonics						
3	DSE	PHY520/ PHY521/ PHY522/ PHY523/ PHY524/ PHY525	**Bucket List:** 1. High Energy Physics Lab 2. Condensed Matter Physics Lab 3. Biomedical Image and Signal Processing Lab 4. Computational Astrophysics 5. Advanced Photonics Lab 6. Material Science Lab	0	0	2	2		6.5
4	ED	PHY512	Entrepreneurship Course	2	0	0	2		6.5
5	Project	PHY513	Dissertation II	0	0	10	10		6.5
Semester Credits							22		

Total credit for 2-year M.Sc. (Physics) = 95

Program Name: **M.Sc. (Physics)**

Program Code: **PHY4201**

Offered by Department of Physics, School of Basic and Applied Sciences, Adamas University

Duration: 2 Years

Academic Year: 2026-27

Syllabus

CORE COURSES (CC) THEORY AND LAB

Paper Name: ***Mathematical Methods***
Paper Code: **PHY451**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To develop a deep understanding of advanced physics principles and their applications in various scientific problems.
2. To enhance skills in mathematical tools, particularly in linear algebra and complex analysis, to solve physical problems.
3. To cultivate expertise in differential equations and special functions relevant to physical theories.
4. To foster proficiency in integral transforms and their applications in solving differential equations.
5. To introduce fundamental concepts of group theory and its relevance in physics.

Course Description:

This course aims to enhance students' understanding of critical mathematical concepts, including linear algebra, complex analysis, differential equations, special functions, integral transforms, and group theory. Through a blend of theoretical and practical applications, students will explore the mathematical frameworks that support physical theories and phenomena. Key topics include vector spaces, tensor analysis, the theory of second-order linear homogeneous differential equations, and integral transforms such as Fourier and Laplace transforms. Additionally, the course will introduce the principles of group theory and its relevance to physics. By the end of the course, students will be equipped with sophisticated mathematical tools to analyze and model complex physical systems, advancing their proficiency in both pure and applied physics.

Course Outcomes

1. **CO1: Recall** and **state** the foundational mathematical structures and tools used in physics, including vector spaces, complex analysis, differential equations, special functions, and group theory.

2. **CO2: Explain** the theoretical underpinnings of linear algebra, complex function theory, Sturm-Liouville systems, and integral transforms with their interconnections across physical applications.

3. **CO3: Apply** mathematical techniques such as Frobenius method, Green's functions, Fourier and Laplace transforms, and representation theory to solve a wide variety of problems in theoretical physics.

4. **CO4: Analyse** the behaviour of second-order differential equations, singularities of complex functions, properties of special functions, and the structure of symmetry groups.

5. **CO5: Evaluate** the appropriateness and effectiveness of various mathematical approaches—such as operator methods, transform techniques, and group symmetries—in modelling and solving advanced physics problems.

Course Content:

Module 1: Linear Vector space and Matrices and Tensor *(10 hours)*

Vectors in function space, Axiomatic definition, linear independence, bases, dimensionality, inner product, Gram-Schmidt orthogonalization, Operators, self-Adjoint and Unitary Operators, Transformation of Operators, Matrices: Representation of linear transformations and change of base, Eigenvalues and eigenvectors, Functions of a matrix; Cayley-Hamilton theorem, commuting matrices with degenerate eigenvalues, Orthonormality of eigenvectors. Hermitian matrix Diagonalization.

Introduction to Tensor, The rank and component of tensor, tensor of higher rank, symmetric and anti-symmetric tensor

Module 2: Complex variables *(10 hours)*

Recapitulation of Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable, single and multiple-valued function, limit and continuity, Differentiation, Cauchy-Riemann equations and their applications, Analytic and harmonic function, Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy's Integral Formula and its corollaries, Series: Taylor and Laurent expansion, Classification of singularities, Branch point and branch cut, Cauchy's Residue theorem and evaluation of some typical real integrals using this theorem.

Module 3: Theory of Second Order Linear Homogeneous Differential Equations *(8 hours)*

Brief introduction to 1st order ODEs and 2nd order Linear ODEs, Singular points, Regular and Irregular singular points, Frobenius method, Fuch's theorem, Linear independence of solutions, Wronskian, second solution. Sturm-Liouville theory, Hermitian Operator, Completeness.

Module 4: Special functions *(10 hours)*

Bessel functions of 1st Kind, Orthogonality, Bessel function of 2nd kind, Generating functions, Spherical Bessel Functions, Legendre polynomials, Orthogonality, Physical interpretation of Generating functions, Associated Legendre's Equation, Spherical Harmonics, Hermite functions, Laguerre Functions.

Module 5: Inhomogeneous differential equations *(5 hours)*

Green's functions technique and its applications to study physical problems.

Module 6: Integral transforms *(8 hours)*

Fourier and Laplace transform and their inverse transforms, Application of Laplace transform, Bromwich integral [use of partial fractions in calculating inverse Laplace transforms], Discrete Fourier Transform, Transform of derivative and integral of a function, Solution of differential equations using integral transforms.

Module 7: Group theory *(7 hours)*

Definitions, Multiplication table, Rearrangement theorem; Isomorphism and homomorphism; Illustrations with point symmetry groups, Group representations: faithful and unfaithful representations, reducible and irreducible representations, Lie groups and Lie algebra with SU(2) as an example.

Reference Books

1. Mathematical Methods for Physicists, G. B. Arfken, H.J. Weber, F. E. Harris, 2013, Elsevier.
2. Differential Equations, George F. Simmons, 2007, Mc. Graw Hill.
3. Mathematical Methods in Physical Sciences, Mary L. Boas, Wiley
4. Matrices and Tensor in Physics, by A. W. Joshi
5. Complex Variables and Applications by, Brown and Churchill.
6. Theory and problems Complex variables, Schaum's outline series M. R. Spiegel.
7. Group Theory (Dover Books on Mathematics) by, W. R. Scot
8. Mathematical Physics, H K Das, S Chand Publisher.
9. Mathematical Methods for Physics and Engineering, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge University Press.
10. Elements of group theory for physicists, by A. W. Joshi

Paper Name: ***Classical Mechanics***
Paper Code: **PHY452**
Credit: **4**
LTP: **4-0-0**

Course Objectives

1. To provide students with a thorough understanding of variational principles, Lagrange's equations, and Hamiltonian mechanics, equipping them with the analytical tools necessary for solving complex problems in classical mechanics.
2. To encourage students to apply theoretical concepts to practical scenarios, fostering critical thinking and problem-solving skills that are essential for advanced studies in physics.
3. To highlight the relevance of classical mechanics to various fields, including engineering, astrophysics, and fluid dynamics, thereby illustrating the interdisciplinary nature of physics.
4. To cultivate students' research capabilities and analytical skills, preparing them for future academic pursuits and professional challenges in physics and related disciplines.

Course Description

This course offers an advanced exploration of classical mechanics, emphasizing the variational principles and their applications in formulating the equations of motion. Students will study Hamilton's and Lagrange's equations, the dynamics of rigid body motion, and the mechanics of small oscillations. Additionally, the course covers the classical mechanics of special relativity, introducing Lorentz transformations, four-vectors, and relativistic dynamics. Special topics may include Lagrangian and Hamiltonian formulations for continuous systems, elements of fluid mechanics, and an introduction to chaos theory. By integrating theoretical knowledge with practical applications, students will develop a comprehensive understanding of advanced mechanics.

Course Outcomes

1. **CO1: Recall** and **state** fundamental principles, formulations, and mathematical tools of classical mechanics, including Lagrangian and Hamiltonian dynamics, small oscillations, and relativistic mechanics.

2. **CO2: Explain** the theoretical foundations and physical implications of variational principles, canonical transformations, and relativistic kinematics within classical mechanics.

3. **CO3: Apply** advanced formulations such as Lagrangian, Hamiltonian, and Hamilton-Jacobi methods to solve dynamic systems involving oscillations, rigid bodies, and relativistic particles.

4. **CO4: Analyse** the role of symmetries, conservation laws, Poisson brackets, and action-angle variables in characterizing the structure and evolution of mechanical systems.

5. **CO5: Evaluate** and **compare** different classical frameworks—including Newtonian, Lagrangian, Hamiltonian, and relativistic approaches—to formulate and interpret the equations of motion for complex systems.

Course Content

Module 1: Variational Principle and Lagrange's Equations *(5 hours)*

Introduction to Hamilton's Principle, Few applications of the technique of Calculus of Variations, Derivation of Lagrange's Equation from Hamilton's principle, Applications of Lagrange's Equations, Advantages of Variational principle formulation, Conservation theorem and symmetry properties.

Module 2: The Hamilton Equations of motion *(6 hours)*

Legendre Transformations and the Hamilton Equations of motion, Cyclic co-ordinates and Conservation Theorems, Applications of Hamiltonian formulation, Derivation of Hamilton's equations from Variational principle, The Principle of Least Action.

Module 3: Canonical Transformations *(6 hours)*

The equations of canonical transformation, Examples of Canonical transformations, The Harmonic Oscillator, Poisson bracket and other Canonical Invariants, Equations of Motion, Infinitesimal Canonical Transformation and Conservation Theorems, Symmetry Groups.

Module 4: Hamilton-Jacobi Theory Action-Angle Variables *(4 hours)*

Hamilton-Jacobi Equations, Harmonic Oscillator problems, Action-Angle variables in 1D system.

Module 5: Rigid Body Motion *(10 hours)*

Degrees of freedom, Orthogonal Transformations and properties of transformation matrices, Euler angles, Euler's Theorems on the motion of a rigid body, Finite and infinitesimal rotations, Rotating co-ordinate system, Coriolis force, Angular Momentum and Kinetic Energy of motion, Moment of Inertia tensor, Principal axis of transformation, solution of rigid body problem using Euler equation of motion, torque free motion of a rigid body, heavy symmetrical top, precession and nutation.

Module 6: Small Oscillations *(4 hours)*

Formulation of the problem, Eigen Value Equations, Principle Axis and Normal Co-ordinates, Free Vibrations of a linear tri-atomic molecule, Forced vibrations and Dissipative forces.

Module 7: Classical mechanics of Special Theory of Relativity *(10 hours)*

Basic postulates, Lorentz transformation, velocity addition, four-vectors, metric tensors, Relativistic Kinematics of Collisions and Many Particle Systems, Relativistic Angular Momentum, Lagrangian Formulation of Relativistic Mechanics, Co-variant Lagrangian formulation.

Special Topics

(O*nly for advanced level interested students, not a compulsory component of curriculum, so no lecture hours are being specified*)
Introduction to Lagrangian and Hamiltonian Formulations for continuous systems and fields: Transition from a discrete to a continuous system, Lagrangian formulation for continuous systems, Hamiltonian formulation, Relativistic Field theory and examples, Noether's Theorem.

Elements of Fluid Mechanics and Navier -Stokes Equation.
Introduction to Chaos: Stable and unstable fixed points, Logistic Map, bifurcation route to chaos.

Reference Books:

1. An introduction to mechanics, D. Kleppner, R.J. Kolenkow, 1973, McGraw-Hill.
2. Introduction to Classical Mechanics, David Morin, Cambridge University Press.
3. Classical Mechanics, H.Goldstein, C.P. Poole, J.L. Safko, 3rdEdn. 2002, Pearson Education.
4. Mechanics, L. D. Landau and E. M. Lifshitz, 1976, Pergamon.
5. The Classical Theory of Fields, L.D Landau, E.M Lifshitz, 4th Edn., 2003, Elsevier.
6. Classical Mechanics, P.S. Joag, N.C. Rana, 1st Edn., McGraw Hall.
7. Classical Mechanics, R. Douglas Gregory, 2015, Cambridge University Press.
8. K.C. Gupta: Classical Mechanics of Particles and Rigid Bodies
9. Solved Problems in classical Mechanics, O.L. Delange and J. Pierrus, 2010, Oxford Press.

Paper Name: ***Quantum Mechanics***
Paper Code: **PHY453**
Credit: **4**
LTP: **4-0-0**

Course Objectives

1. To equip students with a comprehensive understanding of quantum mechanics.
2. To emphasize the mathematical foundations and fundamental postulates of quantum mechanics.
3. To develop students' critical thinking and analytical skills for interpreting quantum mechanical problems.
4. To prepare students for advanced studies and research in physics through practical applications.
5. To foster the ability to solve one-dimensional and three-dimensional quantum mechanical problems.

Course Description

Quantum Mechanics is a fundamental area of Physics that deals with the understanding of the behavior of the subatomic particles under the influence of electric and magnetic forces. This course deals with fundamental concepts and applications of Quantum mechanics and idea about angular momentum.

Course Outcomes

1. **CO1: Recall and explain** fundamental concepts of quantum mechanics, such as wave packets, uncertainty relations, and the basic postulates, including their applications.

2. **CO2: Describe and interpret** the mathematical framework of quantum mechanics, including operators, Hilbert space, and matrix mechanics, and connect these with physical phenomena.

3. **CO3: Solve** quantum mechanical problems, including 1D and 3D potential wells, harmonic oscillators, and angular momentum eigenvalue problems, using appropriate mathematical techniques.

4. **CO4: Analyze** the implications of quantum postulates and symmetries, such as conservation laws and the connection between classical and quantum mechanics, for solving physical systems.

5. **CO5: Evaluate** advanced quantum concepts, such as coherent states, angular momentum, and C-G Coefficients construction, and the Stern-Gerlach experiment, to assess their impact on modern quantum mechanics.

Course Content

Module 1: Recapitulation of Basic Concepts *(6 hours)*

Wave Packets; Different forms of wave packets (e.g., Gaussian, Square wave etc.), Wave packets and Uncertainty relations, Motion of wave packets, Parserval's theorem.

Module 2: Mathematical Formulation of Quantum Mechanics *(12 hours)*

Idea of Hilbert space and Wave functions, Operators, introduction to bra-ket formulation, Representation of operators in discrete bases (Matrix representation), unitary transformations,

Representation in continuous bases (Position and Momentum representation), Parity operator, Matrix mechanics and Wave mechanics.

Module 3: Postulates of Quantum Mechanics *(12 hours)*

Basic postulates, Observables and Operators, Measurements in Quantum Mechanics, Time evolution of a quantum mechanical system, Schrödinger, Heisenberg and interaction picture, Symmetries and conservation laws, Relation between Classical and Quantum Mechanics.

Module 4: One Dimensional Problems *(10 hours)*

Review of potential well problems, δ function potential well and barriers, double δ potential, Application to molecular inversion; Multiple well potential, Kronig-Penney model.One dimensional harmonic oscillator by Operator Method, Coherent States, Landau Level problem.

Module 5: Three Dimensional Problems *(10 hours)*

3-D problems in Cartesian co-ordinate; free particle, Box potential, Delta function potential, Harmonic Oscillator, 3-D problems in Spherical polar co-ordinate; free particle, square well potential, isotropic harmonic oscillator, Hydrogen atom.

Module 6: Angular Momentum *(12 hours)*

Stern-Gerlach experiment for spin $\frac{1}{2}$ particle, Orbital angular momentum, Spin angular momentum, Spin $\frac{1}{2}$ and spin 1 particles, Pauli matrices, Eigenvalues and Eigen functions of $\hat{L}^2$ and $\hat{L}_z$ operator, Spherical harmonics. Addition of angular momenta, Clebsch-Gordan co-efficient.

Special Topics:

(*Only for advanced level learners, not a compulsory component of curriculum, so no lecture hours are being specified*)

Quantum theory of measurement and Time evolution: Double Stern-Gerlach experiment for spin-1/2 system; Schrodinger, Heisenberg and interaction pictures.

Test of validity of the Foundations of Quantum Mechanics: The Copenhagen interpretation, the EPR paradox.

References:

1. Introduction to Quantum Mechanics, David J. Griffith, 2005, Pearson Education.
2. A Text book of Quantum Mechanics, P.M. Mathews and K. Venkatesan, 2nd Ed.,
3. 2010, McGraw Hill.
4. Quantum Mechanics, Robert Eisberg and Robert Resnick, 2nd Edn., 2002, Wiley.
5. Quantum Mechanics, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
6. Quantum Mechanics, Eugen Merzbacher, 2004, John Wiley and Sons, Inc.
7. J.J. Sakurai: Modern Quantum Mechanics
8. S. Gasiorowicz: Quantum Physics.
9. Quantum Mechanics: Theory and Applications. Author: A. *Ghatak*, S. *Lokanathan* Published by Springer Netherlands.

Paper Name: ***Classical Electrodynamics***
Paper Code: **PHY466**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Understand the fundamentals of electrostatics and magnetostatics, including scalar and vector potentials, gauge transformations, and multipole expansions.
2. Analyze complex electromagnetic phenomena through Maxwell's equations and their applications in both stationary and moving media.
3. Explore radiation mechanisms from moving charges, focusing on near-field and far-field approximations, and various radiation types.
4. Apply the principles of relativistic electrodynamics to describe the behavior of charged particles and fields under high-velocity conditions.

Course Description:

Classical electrodynamics is a branch of physics that studies the behaviour of charges and currents and their interactions. In this course, both the non-relativistic as well relativistic electrodynamics is included.

Course Outcomes:

1. **CO1: Recall and summarize** the fundamental laws and formulations of classical electrodynamics, including Maxwell's equations, radiation theory, and relativistic field concepts.

2. **CO2: Explain** the physical meaning and mathematical structure of electromagnetic potentials, radiation from moving charges, energy-momentum conservation, and gauge transformations.

3. **CO3: Apply** Maxwell's equations, Jefimenko's formulas, Liénard–Wiechert potentials, and relativistic transformations to compute electromagnetic fields and radiative properties in dynamic situations.

4. **CO4: Analyse** electromagnetic field interactions with matter, near and far-field radiation patterns, radiation reaction forces, and the relativistic covariance of field equations.

5. **CO5: Evaluate** various classical electrodynamics problem-solving techniques—such as multipole expansion, variational principles, relativistic formulations, and radiation analysis—in terms of their applicability, limitations, and physical interpretations.

Course Content:

Module 1: Electrostatics and Magnetostatics *(12 hours)*

Scalar and vector potentials; Gauge transformations; Multipole expansion of (i) scalar potential and energy due to a static charge distribution (ii) vector potential due to a stationary current distribution. Calculations of dipole and Quadrupole moment tensor due to different charge distributions. Electrostatic and magnetostatic energy. Poynting's theorem. Maxwell's stress tensor (both in presence and absence of di-electrics), electromagnetic momentum, Radiation pressure.

Module 2: Maxwell's Equations in stationary and moving media *(6 hours)*

Quantitative discussion.

Module 3: Fields due to time dependent charge and current distributions *(12 hours)*

Solution of inhomogeneous wave equations without green's function, Jefimenko's equations. Near field and far-field approximation, Larmor's formula.

Module 4: Radiation from moving point charges *(12 hours)*

Lienard-Wiechert potentials, Fields due to a charge moving with uniform velocity, Fields due to an accelerated charge, Radiation at low velocity, Larmor's formula and its relativistic generalization, Radiation when velocity (relativistic) and acceleration are parallel, Bremsstrahlung, Radiation when velocity and acceleration are perpendicular, Synchrotron radiation, Cherenkov radiation (qualitative treatment only). Thomson and Compton scattering.

Module 5: Radiation Reaction *(12 hours)*

Radiation reaction from energy conservation, Problem with Abraham-Lorentz formula, Limitations of Classical Electrodynamics.

Module 6: Relativistic Electrodynamics *(12 hours)*

Idea of a classical field as a generalized coordinate. Euler-Lagrange equation for the field from the Lagrangian density. The field momentum and the Hamiltonian density. Poisson brackets for the fields. Equation of motion in an electromagnetic field; Electromagnetic field tensor, covariance of Maxwell's equations; Maxwell's equations as equations of motion; Lorentz transformation of fields, Lorentz invariants, Symmetric and anti-symmetric field tensor, $F_{\mu\nu}$ and $G_{\mu\nu}$ .Covariance of Lorentz force equation and the equation of motion of a charged particle in an electromagnetic field; The generalized momentum; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field.

Special Topics:

(*Only for advanced level learners, not a compulsory component of curriculum, so no lecture hours are being specified*)

Introductory Plasma Physics

Definition of plasma; its occurrence in nature; Dilute and dense plasma; Uniform but time dependent magnetic field: Magnetic pumping; Static non-uniform magnetic field: MHD equations, Pinched plasma; Plasma Oscillations.

Reference Books:

1. J.D. Jackson: Classical Electrodynamics
2. W.K.H. Panofsky and M. Phillips: Classical Electricity and Magnetism
3. J.R.Reitz, F.J. Milford and R.W. Christy: Foundations of Electromagnetic theory
4. D.J. Griffiths: Introduction to Electrodynamics
5. Classical Electromagnetic Radiation, Mark A. Heald and J. B. Marion, Dover Books on Physics
6. Modern Problems in Classical Electrodynamics, C. A. Brau
7. Classical Electrodynamics, Walter Greiner and D. A. Bromley

Paper Name: ***Advanced Quantum Mechanics***
Paper Code: **PHY467**
Credit: **4**
LTP: **4-0-0**

Course Objectives

1. To provide a comprehensive understanding of approximation methods in quantum mechanics, enabling students to analyze complex quantum systems.
2. To develop problem-solving skills in applying various approximation techniques like perturbation theory, WKB approximation, and the variational method.
3. To explore advanced concepts such as time-dependent perturbation theory, scattering theory, symmetries, and relativistic quantum mechanics.
4. To apply quantum mechanics principles to analyze and solve problems involving atomic systems, scattering processes, and particle interactions.

Catalogue Description:

Quantum Mechanics is one of the most fundamental theoretical formulations of Physics, which deals with the microscopic world of atomic and subatomic particles. This course actually deals with the advanced theories like approximation methods, scattering theory, symmetries etc. to understand nature at the microscopic level. We also study the basics of relativistic quantum mechanics and necessity to go over to the regime of Quantum Field Theory.

Course Outcomes:

1. **CO1: Recall and describe** key approximation methods in quantum mechanics, such as perturbation theory, WKB approximation, and variational methods, and their applications to physical systems.

2. **CO2: Explain** advanced quantum mechanical concepts, including time-dependent perturbation theory, quantum symmetries, and scattering theory, and their relevance to physical phenomena.

3. **CO3: Apply** quantum mechanical methods, such as Fermi's Golden Rule, Born approximation, and variational principles, to solve practical problems in atomic, molecular, and scattering systems.

4. **CO4: Analyze** the implications of symmetries, conservation laws, and the behavior of identical particles in quantum systems, including their role in degeneracies and wave function characteristics.

5. **CO5: Evaluate** the limitations and consequences of relativistic quantum mechanics, including Klein-Gordon and Dirac equations, and explore their implications for antiparticles and spin dynamics.

Course Content

Module 1: Approximation methods in quantum mechanics *(18 hours)*

Time independent perturbation theory: (both non-degenerate and degenerate), First and Second order correction in energy Eigenvalues, and first order corrections in energy Eigen functions. Degenerate perturbation theory, application to one-electron system, Relativistic mass correction, Spin-orbit coupling (L-S and J-J coupling), Zeeman effect, Stark effect.

WKB Approximation: Quantisation rule, General formalism, Bound states for potential wells with No rigid walls/ with One rigid wall/ with Two rigid walls, tunnelling through a barrier, qualitative discussion of α decay.

Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.

Module 2: Time dependent perturbation theory *(10 hours)*

The pictures of Quantum Mechanics, Schrodinger picture, Heisenberg's picture and Interaction picture. Theoretical framework of time-dependent perturbation theory, Transition probability for a Constant perturbation and Harmonic perturbation, Fermi Golden rule, Adiabatic and Sudden approximations.

Quantum Adiabatic Theorem, Concept of Berry Phase and relevance with Zak phase.

Module 3: Scattering Theory *(10 hours)*

Scattering cross-section, lab frame and CM frame, Scattering amplitude and differential cross section, Green's function technique in scattering phenomena, Born approximation, Validity of Born Approximation, Partial Wave analysis for elastic scattering, scattering of identical particles.

Module 4: Symmetries in quantum mechanics *(6 hours)*

Conservation laws and degeneracy associated with symmetries; Continuous symmetries, space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries, parity and time reversal.

Module 5: Identical Particles *(4 hours)*

Meaning of identity and consequences; Symmetric and anti-symmetric wave functions; Slater determinant; Symmetric and anti-symmetric spin wave functions of two identical particles.

Module 6: Relativistic Quantum Mechanics *(10 hours)*

Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of matrices; Charge conjugation; Normalization and completeness of spinors. Failure of relativistic quantum mechanics

Reference Books:

1. L.I. Schiff: Quantum Mechanics
2. Quantum Mechanics, Nouredine Zettili, John Wiley and Sons Ltd.
3. Quantum Mechanics, David J. Griffiths
4. J.J. Sakurai: Advanced Quantum Mechanics
5. C. Cohen-Tannoudji, B. Dier, and F. Laloe: Quantum Mechanics vol. 1 and 2
6. E. Merzbacher: Quantum Mechanics
7. Messiah: Quantum Mechanics, Vol. II
8. Quantum Mechanics, Bransden and Joachain, Pearson Education.
9. J.D. Bjorken and S.D. Drell: Relativistic Quantum Mechanics
10. F. Halzen and A.D. Martin: Quarks and Leptons
11. W. Greiner: Relativistic Quantum Mechanics
12. A. Lahiri and P.B. Pal: A First Book of Quantum Field Theory

Paper Name: ***Advanced Statistical Mechanics***
Paper Code: **PHY468**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce the fundamental concepts of statistical mechanics and establish the relationship between statistics and thermodynamics.
2. To develop an understanding of different statistical ensembles and their applications to classical and quantum systems.
3. To analyze the behavior of ideal and real gases, phase transitions, and mean field theory using statistical mechanics.
4. To explore the advanced topics of non-equilibrium statistical mechanics, including irreversible processes and fluctuation-dissipation theorem.

Catalogue Description:

This course aims to impart knowledge about principles and applications of Statistical Mechanics in physics. Statistical Mechanics is a phenomenological subject and closely connected with Kinetic theory of gases and Thermodynamics. Students will be able to know different types on ensembles and the use of ensemble for studding different problems. Also, student will learn about Quantum Statistical Mechanics and its applications in real physical problems. In addition, students will understand about ideal Bose Gas, Bose-Einstein Condensation, ideal Fermi gas and statistical theories of phase transitions. At the end we have introduced non-equilibrium statistical mechanics briefly into this course. The course consists of lectures and tutorial classes. We mainly focus on the development of fundamental concepts which could be helpful to solve various other problems. Regular class tests will be taken and some special classes will be arranged for student presentation and for student-teacher interaction.

Course Outcome:

1. **CO1: Recall** the fundamental principles of statistical mechanics, including macrostates, microstates, statistical ensembles, and Boltzmann's postulate of entropy.

2. **CO2: Explain** the concepts of classical statistical mechanics, such as the microcanonical, canonical, and grand canonical ensembles, and their applications to thermodynamic systems.

3. **CO3: Apply** quantum statistical mechanics, including Bose-Einstein and Fermi-Dirac distributions, to analyze the thermodynamic behavior of ideal Bose and Fermi systems.

4. **CO4: Analyze** interacting systems using methods such as the virial expansion, cluster expansion, and phase transitions, including the Ising model and critical exponents.

5. **CO5: Evaluate** the dynamics of non-equilibrium systems through classical linear response theory, fluctuation-dissipation theorem, and equations such as the Master Equation and Fokker-Planck Equation.

Course Content:

Module 1: Basic Introduction *(5 hours)*

Objective of statistical mechanics. Macrostates and microstates, phase space, Contact between statistics and thermodynamics, statistical ensembles. Ergodic hypothesis, postulate of equal a priori probability (PEAP) and equality of ensemble average and time average. Boltzmann's postulate of entropy. Counting the number of microstates in phase space. Liouville's Theorem.

Module 2: Classical Statistical Mechanics *(15 hours)*

(i) *Microcanonical Ensemble*: Description, Probability distribution function, Different properties, Thermal and Mechanical interaction, Equation of state, Entropy of a classical ideal gas, Gibb's paradox, spin 1/2 particles in an external magnetic field.

(ii) *Canonical Ensemble:* System in contact with a heat reservoir, expression of entropy, canonical partition function, Equation of State, Average energy, Magnetization of spin 1/2 particles in an external magnetic field. Helmholtz free energy, fluctuation of internal energy.

(iii) Grand Canonical Ensemble: System in contact with a particle reservoir, Chemical potential, Grand potential and Grand canonical partition function, fluctuation of particle number. Chemical potential of ideal gas.

Module 3: Statistical Mechanics for Interacting Systems: *(8 hours)*

Equation of state of real gas, Cluster expansion for a classical gas. Virial expansion of the equation of state, Evaluation of the virial coefficients,

Module 4: Quantum statistical mechanics *(15 hours)*

(i) Density Matrix, Quantum Liouville's theorem, Density matrices for micro canonical, canonical and grand canonical systems, Simple examples of density matrices, one electron in a magnetic field, particle in a box, Identical particles, B-E and F-D distributions.

(ii) *Ideal Bose Systems:* Thermodynamic behaviour of an ideal Bose Gas, Equation of state, Bose-Einstein Condensation.

(iii) *Ideal Fermi System*: Equation of state of ideal Fermi gas; Fermi gas at finite T.

Module 5: Phase Transition and Mean Field Theory *(10 hours)*

Ising model: partition function for one dimensional case; Chemical equilibrium and Saha ionisation formula. Phase transitions: first order and continuous, critical exponents and scaling relations. Calculation of exponents from Mean Field Theory and Landau's theory, upper critical dimension. Renormalisation Group.

Module 6: Non-equilibrium Statistical Mechanics *(5 hours)*

Irreversible processes, Classical Linear Response Theory, Brownian Motion, Master Equation, Fokker-Planck Equation, Fluctuation-Dissipation Theorem.

Reference Books:

1. F. Reif: Fundamentals of Statistical and Thermal Physics, McGraw-Hill.
2. R.K. Pathria: Statistical Mechanics, Elsevier
3. K. Huang: Statistical Mechanics, Wiley Student edition
4. F. Mandl: Statistical Physics
5. Statistical Mechanics, F. Schwabl, Springer international edition.
6. Statistical Mechanics, R. Feynman

Paper Name: *Atomic and Molecular Spectroscopy*
Paper Code: PHY500
Credit: 4
LTP: 4-0-0

Course Objectives:

1. To develop a deep understanding of the structure of atoms and the origin of their spectral lines, including relativistic and quantum mechanical effects.
2. To analyze the behavior of atomic systems under external electromagnetic fields and understand coupling mechanisms in multi-electron atoms.
3. To explore the fundamental principles and applications of molecular spectroscopy across various regions of the electromagnetic spectrum.
4. To examine the role of symmetry and group theory in the analysis of molecular vibrations and spectroscopic transitions.
5. To prepare students for advanced applications of spectroscopy in experimental, analytical, and research-oriented contexts.

Course Description:

This course provides a comprehensive understanding of the interaction of electromagnetic radiation with atoms and molecules. It begins with the quantum mechanical foundation of atomic structure, covering relativistic corrections, external field effects, and multi-electron systems. The course further explores various branches of molecular spectroscopy—including microwave, infrared, Raman, spin resonance, and Mössbauer spectroscopy—alongside a foundational introduction to group theory and its role in interpreting molecular vibrations and transitions. The content bridges theoretical formalism with experimental applications, preparing students for research and advanced spectroscopy techniques.

Course Outcomes:

1. **CO1: Explain** the fine and hyperfine structures of hydrogen-like atoms including relativistic effects, and construct appropriate term symbols.

2. **CO2: Apply** the vector atom model to alkali spectra and analyze the effects of external fields such as Stark and Zeeman on atomic energy levels.

3. **CO3: Describe** atom–radiation interaction processes and calculate transition probabilities using Einstein coefficients and selection rules.

4. **CO4: Interpret** rotational, vibrational, Raman, spin resonance, and Mössbauer spectra and relate spectral patterns to molecular structure**.**

5. **CO5: Apply** group theory to molecular vibrations and predict spectroscopic transitions using character tables and symmetry analysis.

Course Content:

Atomic Spectroscopy

Module I: One-Electron System *(7 Hours)*

Fine structure of Hydrogen Atom: relativistic mass correction, spin–orbit coupling, Darwin term, Lamb shift and its physical significance, Hyperfine structure and isotope shifts, Term symbols for hydrogen-like systems

Module II: Vector Atom Model and Alkali Spectra *(6 Hours)*

Vector model of angular momentum, Application to alkali atoms (e.g., sodium, potassium), Fine structure doublets and selection rules, Spectral line intensities and term symbol assignments

Module III: Interaction with Electromagnetic Radiation *(6 Hours)*

Classical treatment of radiation fields, Quantization of the electromagnetic field, Einstein coefficients, dipole approximation, selection rules, Transition rates for absorption and emission, Spontaneous and stimulated emission mechanisms

Module IV: External Fields and Perturbations *(6 Hours)*

Stark effect, Zeeman effect: normal and anomalous, Paschen–Back effect, Vector atom model of angular momentum in external fields

Module V: Two-Electron Systems *(3 Hours)*

Schrödinger equation for two-electron atoms, Exchange symmetry: para and ortho states, Ground and excited state configurations, Term symbols and singlet–triplet splitting, Pauli exclusion principle and total spin

Module VI: Many-Electron Atoms and Coupling Schemes *(6 Hours)*

Central field approximation, Hartree–Fock methods, L–S coupling and J–J coupling, Hund's rules and exchange degeneracy, Lande Interval Rule, Construction of symmetric and antisymmetric wavefunctions, Symmetrization postulate and Pauli principle in multi-electron systems

Molecular Spectroscopy

Module I: General Concept *(6 Hours)*
General nature of molecular structure, Born-Oppenheimer approximation for diatomic molecule, Electronic structure, Approximation methods for construction of wave functions, LCAO approach, symmetries and shapes of electronic orbital.

Microwave spectroscopy *(6 Hours)*

Rotation of molecules, rotational spectra for diatomic and polyatomic molecules.

Infrared spectroscopy *(5 Hours)*

Vibration of diatomic molecule, rotational-vibrational spectra, vibration of polyatomic molecules.

Raman spectroscopy *(4 Hours)*

Rotational and vibrational Raman spectra, polarization of light and Raman effect, structure determination.

Spin resonance spectroscopy *(4 Hours)*

NMR spectroscopy for hydrogen and other nuclei, ESR spectroscopy.

Mossbauer spectroscopy *(2 Hours)*

Principle and applications.

Group Theory in Spectroscopy *(8 Hours)*

Molecular symmetry; Matrix representation of the symmetry elements of a point group; Reducible and irreducible representations; Character tables for C2v and C3v point groups; Normal coordinates and normal modes; Application of group theory to molecular vibration

References:

1. B.H. Bransden and C.J. Joachain: Physics of Atoms and Molecules
2. R. Shankar: Principles of Quantum Mechanics
3. C.B. Banwell: Fundamentals of Molecular Spectroscopy
4. G.M. Barrow: Molecular Spectroscopy
5. K. Thyagarajan and A.K. Ghatak: Lasers, Theory and Applications
6. B.H. Eyring, J. Walter and G.E. Kimball: Quantum Chemistry
7. H. Herzberg: Spectra of Diatomic Molecules

8. B.B. Laud: Lasers and Non-linear Optics

Paper Name: ***Solid State Physics***
Paper Code: **PHY501**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce students to the fundamental concepts of crystal structure, lattice vibrations, and the theory behind electron diffraction.
2. To provide a comprehensive understanding of free electron models, energy bands, and their application to the study of solid-state materials.
3. To explore the transport, dielectric, magnetic, and superconducting properties of solids and their theoretical foundations.
4. To familiarize advanced learners with special topics such as liquid crystals, polymers, and imperfections in solids.

Catalogue Description:

This course aims to impart knowledge of various properties of solids, its origin, understanding, characteristics and application to interdisciplinary fields.

Course Outcome:

1. **CO1; Define** the fundamental concepts of crystal structures, diffraction, and lattice vibrations.
2. **CO2: Explain** the theoretical models like Einstein and Debye models, Boltzmann transport equation, and their applications to specific heat and transport properties.
3. **CO3: Apply** theoretical principles to solve problems involving electron diffraction, energy band structures, and transport mechanisms in solids.
4. **CO4: Analyze** the behavior of solids, including their electronic, dielectric, and transport properties, by utilizing established theoretical models.

5. **CO5: Evaluate** the impact of magnetism and superconductivity on the properties of materials through critical examination of quantum theories.

Course Content

Module 1: Crystal Structure, Electron Diffraction and Lattice vibrations *(12 hours)*

Recapitulation of crystal structures, Bravais lattices, examples of simple crystal structure, amorphous solids and liquids.
Bragg's law, scattering from an atom and a crystal, reciprocal lattice and Bragg's law, electron and neutron diffraction.
Elastic waves, Specific heat: Einstein and Debye models, phonon and lattice waves, thermal conductivity

Module 2: Free Electron model and Energy bands in solids *(14 hours)*

Free electron gas, electrical conductivity, electronic specific heat, Fermi surface, thermal conductivity, thermionic emission, failure of free electron model.
Energy bands in solids, Bloch theorem, nearly free electron model, Tight-binding model, density of states, metal, insulators and semiconductors, crystal momentum, effective mass and hole.

Module 3: Transport and Dielectric properties of Solids *(14 hours)*

Boltzmann Transport Equation, Electrical conductivity, Relaxation time approximation, Impurity Resistivity, Friedel Sum rule, Thermal Conductivity, Thermoelectricity, Seebeck and Peltier Effect. Hall Effect.
Dielectric constant and polarizability, local field, ionic polarizability, electronic polarizability, Piezoelectricity and Ferroelectricity

Module 4: Magnetism and Superconductivity *(16 hours)*

Origin of magnetism; Quantum theory of atomic diamagnetism, Landau diamagnetism (qualitative discussion), Quantum theory of paramagnetism, case of rare-earth and iron-group ions, quenching of orbital angular momentum, Van-Vleckparamagnetism and Pauli paramagnetism, Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction, ferromagnetic domains; Ferrimagnetism and anti-ferromagnetism.
Phenomenological description of superconductivity, perfect diamagnet, Effect of Magnetic field on Superconductivity, Meissner effect; Type-I and type-II superconductors, Specific heat, energy gap and isotope effect, Flux quantisation; a.c. and d.c. Josephson effect.

Special Topics

(*only for advanced level learners, not a compulsory component of curriculum, so no lecture hours are being specified*)

- Liquid crystals: an introduction
- Polymers
- ESR and NMR in Chemistry
- Biophysics: an introduction
- Nucleic Acid
- Protien
- Imperfection and defects in solids

Reference Books:

1. Introduction to Solid State Physics by Charles Kittel
2. Solid State Physics by Neil W. Ashcroft and N. David Mermin
3. Solid State Physics: Structure and Properties of Materials by M.A. Wahab
4. Magnetism in Condensed Matter by Stephen Blundell
5. Introduction to Superconductivity by Michael Tinkham

Paper Name: **Advanced Physics Lab**
Paper Code: **PHY502**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. To introduce advanced experimental techniques in spectroscopy, magnetism, optics, and electronic communication.
2. To enable students to understand and analyze magnetic and optical properties through real-time instrumentation like ESR and interferometry.
3. To familiarize students with the principles of signal modulation and filtering through both analog and digital systems.
4. To develop students' ability to design, build, and test various multivibrator circuits using transistors and timer ICs.
5. To foster skills in interpreting, evaluating, and validating experimental results by linking them to theoretical models.

Course Description:

This lab course offers advanced experimental exposure to the fields of magnetism, optics, molecular spectroscopy, analog communication, and multivibrator circuits. Students will gain practical knowledge through the investigation of magnetic parameters using hysteresis tracers, quantum effects via ESR and Zeeman spectroscopy, and wave interference using Michelson's interferometer. The course further integrates signal modulation techniques and electronic circuit design for multivibrators, thereby developing hands-on expertise and analytical reasoning in experimental physics.

Course Outcomes:

1. **CO1**: **Recall and define** key concepts of magnetic, optical, and spectroscopic phenomena, as well as communication principles relevant to the lab experiments.

2. **CO2**: **Explain** the working principles and functionalities of experimental setups such as ESR spectrometers, Michelson interferometers, modulation circuits, and filter networks.

3. **CO3**: **Apply** experimental techniques to determine physical quantities such as Lande-g factor, coercive field, vibrational frequencies, and wavelength of light sources.

4. **CO4**: **Analyze** response behavior and frequency characteristics of filters and multivibrator circuits; interpret Zeeman splitting patterns and modulation waveforms.

5. **CO5**: **Evaluate** experimental results in comparison with theoretical expectations, assessing the accuracy and limitations of instrumentation and measurement techniques.

Course Content

Experiment 1: Determination of magnetic parameters (Coercive field, residual magnetization and saturation of magnetization) of a Ferromagnetic substance by using *Hysteresis Loop Tracer setup*
Experiment 2: Determination of Lande-g factor by using Electron Spin Resonance Spectroscopy.
Experiment 3: Determination of wavelength of a monochromatic source by using Michelson's Interferometer [Table top setup]
Experiment 4: *Study of Zeeman Effect.*
Experiment 5: *Study of Vibrational Coarse Structure of I2 molecule.*
Experiment 6:
i. Study of Low pass and High pass symmetric T-section filters.
ii. Study of Low pass and High pass symmetric π-section filters.
Experiment 7: Study of Amplitude modulation and demodulation.
Experiment 8: Study of Frequency modulation and demodulation.
Experiment 9: Design and study of an Astable, Monostable and Bi-stable multivibrator by using transistor.
Experiment 10: Design and study of an Astable, Monostable and Bi-stable multivibrator by using 555

Paper Name: ***Nuclear And Particle Physics***
Paper Code: **PHY511**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To understand the fundamental properties of nuclear forces, binding energy, and nuclear structure.
2. To analyze two-body bound states and scattering phenomena, focusing on the deuteron and low-energy scattering.
3. To study beta decay processes and weak interactions, including experimental methods and selection rules.
4. To evaluate nuclear reactions, fission processes, and the classification of elementary particles in the context of the Standard Model.

Catalogue Description

Nuclear physics is a fundamental area of physics which includes basic constituent of matter and their interactions. The subject deals with the nuclear interactions, properties and relevant decay processes and its application in present day research. Course contains current research on nucleon properties and fundamental particles. Particle physics also constitutes a major part of the curse. Symmetries and fundamental laws of nature are included.

Course Outcomes:

1. **CO1: Recall** the fundamental nuclear properties, characteristics of nuclear forces, and experimental methods for determining nuclear size and moments.

2. **CO2: Explain** the theoretical concepts behind nuclear forces, deuteron properties, and beta decay processes, including Fermi and Gamow-Teller transitions.

3. **CO3: Apply** theoretical models like the liquid drop, shell, and collective models to interpret nuclear binding energy and reactions, including fission.

4. **CO4: Analyze** particle classification under the Standard Model, symmetry principles, and the quark model to understand properties and interactions of elementary particles.

5. **CO5: Evaluate** the implications of scattering experiments, beta decay parity non-conservation, and neutrino oscillation data to validate theoretical predictions.

Course Content

Module 1: Nuclear Properties *(8 hours)*

Nuclear properties, Characteristics of strong nuclear force, Nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces, nuclear size, nuclear radius and charge distribution, nuclear form factor, mass and binding energy, Angular momentum, parity and symmetry, Magnetic dipole moment and electric Quadrupole moment, experimental determination, Rabi's method

Module 2: Two body Bound State and Scattering State *(8 hours)*

Properties of deuteron, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces, Schrödinger equation and its solution for ground state and excited state of deuteron. Comparison between potential energies of ground and excited states of deuteron.

Low energy n-p scattering data, Partial wave analysis and phase shifts, scattering cross section, scattering length, magnitude of scattering length and strength of scattering, Significance of the sign of scattering length; effective range theory, low energy p-p scattering.

Module 3: Beta Decay *(8 hours)*

Weak interaction, definition of beta decay, Emission of electron and electron capture, Fermi's theory of beta decay. Selection rules, Selection rules for Fermi and Gamow-Teller transitions, Forbidden and allowed transition rule for beta emission. Kurie Plot, Parity non-conservation in beta decay, Wu's experiment.

Module 4: Nuclear Structure *(8 hours)*
Bethe-Weizsäcker binding energy/mass formula for nuclear binding energy, Study of nuclear experimental binding energy graph, Liquid drop model of nucleus, Fermi Gas model of nucleus, Shell model and nuclear spectra, Collective model.

Module 5: Nuclear Reaction and Fission *(8 hours)*

Different types of reactions, Quantum mechanical theory, Resonance scattering and reactions, Breit-Wigner dispersion relation; Compound nucleus formation and break-up. Reaction cross section, scattering and reaction cross section, Optical model; Nuclear fission: Sponteneous fission, liquid drop model of fission, Application of nuclear physics.

Module 6: Particle Physics and Strong Interactions *(14 hours)*

Concept of Standard Model, Classification of Elementary particles. Mesons, Baryons, leptons, basic forces of nature and their characteristics, coupling constants, Feynman diagram of basic interactions, mediators, properties of neutrinos, characteristics of strange particles, internal quantum numbers, baryon numbers, lepton number, hypercharge, isospin quantum number and isospin symmetry in strong interaction, Eightfold way, meson Octet, baryon Octet, baryon decuplet, Quark model for baryon and mesons in Eightfold scheme, Gellman-Nishijima formula, color quantum number and quark confinement in QCD scheme (Qualitative feature). Symmetries and conservation laws. Elementary particle decays and relevant conservation laws, forbidden and allowed decay of particles. Magnetic moment of hadrons.

Module 7: Neutrino Physics *(4 hours)*

Neutrino mass, Neutrino Oscillations, Atmospheric neutrino oscillations, Solar Neutrino Oscillation, Oscillation probability.

Reference Books

1. E. Fermi: Nuclear Physics.
2. R.R. Roy and B.P. Nigam: Nuclear Physics
3. S.N. Ghoshal: Atomic and Nuclear Physics (Vol. 2)
4. D.H. Perkins: Introduction to High Energy Physics
5. D.J. Griffiths: Introduction to Elementary Particles
6. W.E. Burcham and M. Jobes: Nuclear and particle Physics

DISCIPLINE SPECIFIC ELECTIVE COURSES (THEORY AND LAB)

Specialization Options: Condensed Matter Physics/ High Energy Physics/ Biomedical Instrumentation/ Nanoscience and Nano-materials / Astrophysics / Quantum Electronics and Photonics

Paper Name: ***Physics Quantum Information Theory and Quantum Computing***

Paper Code: **PHY456**

Credit: **4**

LTP: **4-0-0**

Course Objectives:

- To introduce the principles of quantum mechanics that underlie quantum computation and quantum information.
- To develop mathematical and conceptual tools for understanding quantum states, entanglement, and quantum gates.
- To explore quantum algorithms and the advantage of quantum computing over classical computing.
- To understand error correction, decoherence, and the role of quantum cryptography.
- To equip students with foundational knowledge required for advanced study or research in quantum technologies.

Course Outcomes (COs):

After the completion of this course, students will be able to-

CO1: **Explain** the fundamental concepts of quantum mechanics relevant to information theory and computing.
CO2: **Apply** mathematical tools to represent quantum states, quantum gates, and operations using linear algebra and Dirac notation.
CO3: **Analyze** quantum algorithms such as Deutsch-Jozsa, Grover's, and Shor's algorithms to understand their advantages over classical counterparts.
CO4: **Evaluate** the principles of quantum error correction, decoherence, and quantum cryptographic protocols.
CO5: **Perform** basic simulations or analyses of quantum circuits and interpret their behavior using available quantum computing platforms or software tools.

Course Content:

Module I: Foundations of Quantum Information

12 Lectures

Classical bits vs. quantum bits (qubits), Quantum states and density matrices, Dirac notation, inner and outer products, Postulates of quantum mechanics, Tensor product and multi-qubit systems, Bloch sphere representation

Module II: Quantum Gates and Circuits

12 Lectures

Single qubit gates: Pauli gates, Hadamard, Phase, π/8 gate, Multi-qubit gates: CNOT, Toffoli, Swap, Unitary transformations and quantum circuits, Measurement in quantum systems, Universal quantum gates, Quantum teleportation and superdense coding

Module III: Quantum Algorithms

13 Lectures

Quantum parallelism and interference, Deutsch and Deutsch-Jozsa Algorithm, Bernstein-Vazirani Algorithm, Grover's Search Algorithm, Simon's Algorithm, Shor's Factoring Algorithm (conceptual)

Module IV: Quantum Error Correction and Decoherence

10 Lectures

Errors in quantum computation, Classical vs. quantum error correction, Bit flip, phase flip, and bit-phase flip codes, Shor's 9-qubit code and Steane's 7-qubit code, Decoherence and fault-tolerant computation

Module V: Quantum Cryptography and Emerging Technologies

11 Lectures

No-cloning theorem, Quantum key distribution (BB84 protocol), EPR paradox and Bell's inequality, Entanglement and its quantification, Introduction to quantum simulation and cloud-based quantum computing (e.g., IBM Q, Qiskit basics)

Reference Books:

1. **Michael A. Nielsen and Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press
2. **N. David Mermin**, *Quantum Computer Science: An Introduction*, Cambridge University Press

3. **John Preskill**, *Lecture Notes on Quantum Computation* (Available online: www.theory.caltech.edu/people/preskill)
4. **Rieffel and Polak**, *Quantum Computing: A Gentle Introduction*, MIT Press
5. **S. Das and A.C. Mitra**, *Quantum Mechanics and Quantum Computation*, Narosa Publishing
6. **Qiskit Textbook**, *Learn Quantum Computation Using Qiskit* (https://qiskit.org/textbook/)

Course Title: Physics of Emerging Electronic Devices
Course Code: PHY461
Credits: 4
L–T–P: 4–0–0

Course Objectives

1. To develop a fundamental understanding of semiconductor physics, carrier transport, interfacial electrostatics, and electrochemical phenomena relevant to modern electronic and bioelectronic devices.

2. To explore the physical principles governing biosensors, field-effect sensing devices, and semiconductor–electrolyte interfaces, including charge transfer, screening, and noise mechanisms.

3. To understand low-dimensional systems, quantum effects, and advanced materials used in sensing and nanoelectronic applications.

4. To investigate the physics of flexible and soft electronic systems, including mechanical–electrical coupling, organic semiconductors, and strain-dependent transport phenomena.

5. To understand the physical principles, performance characteristics, and applications of modern energy conversion, storage, and harvesting devices, including solar cells, batteries, supercapacitors, fuel cells, and nanogenerators.

Course Outcomes

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

CO1: Recall and explain the fundamental principles of semiconductor physics, electrochemical interfaces, carrier transport, and energy conversion processes relevant to modern electronic devices.

CO2: Describe the operating mechanisms of biosensors, BioFETs, flexible electronics, neuromorphic devices, and energy devices, including electrostatic, electrochemical, mechanical, and quantum effects.

CO3: Apply concepts of charge transport, semiconductor physics, electrochemical kinetics, and device modeling to analyze the behavior of sensing, memory, and energy-related devices.

CO4: Analyze the influence of screening effects, quantum confinement, noise, mechanical deformation, and switching dynamics on device performance, sensitivity, and reliability.

CO5: Evaluate emerging technologies such as BioFETs, flexible electronics, memristive synaptic devices, photovoltaic systems, energy storage devices, and nanogenerators in terms of efficiency, scalability, sustainability, and technological limitations.

Course Description

This course introduces the fundamental physics of emerging electronic, bioelectronic, neuromorphic, and energy devices. It covers semiconductor physics, charge transport, electrochemical interfaces, biosensors, field-effect sensing devices, low-dimensional materials,

and quantum effects. The course also explores flexible and soft electronics, including mechanical–electrical coupling and charge transport in disordered materials.

Special emphasis is given to neuromorphic devices such as memristors and synaptic transistors, focusing on resistive switching, plasticity, and energy-efficient computing. The course further examines energy conversion, storage, and harvesting technologies, including solar cells, batteries, supercapacitors, fuel cells, and nanogenerators. Overall, it provides an interdisciplinary foundation for modern research in nanoelectronics, bioelectronics, neuromorphic systems, and sustainable energy technologies.

Course Content

Module 1: Semiconductor and Interface Physics (10 Hours)

- Energy band structure and carrier statistics (Fermi–Dirac distribution)
- Charge transport mechanisms: drift–diffusion and hopping transport
- Semiconductor–electrolyte interface: band bending and surface states
- Interface traps and recombination processes
- Poisson–Boltzmann equation (qualitative idea)
- Debye screening length and electrostatic potential in electrolytes

Module 2: Electrochemical and Biosensing Physics (8 Hours)

- Electrochemical potential and Nernst equation
- Charge transfer mechanisms: diffusion and reaction kinetics
- Butler–Volmer equation (qualitative treatment)
- Electrical double layer: Helmholtz and diffuse layer
- Sensitivity, selectivity, and response time
- Noise in biosensors: thermal noise, shot noise, and 1/f noise

Module 3: Field-Effect Biosensors (10 Hours)

- MOSFET physics (advanced perspective)
- Ion-Sensitive Field-Effect Transistors (ISFET) and Biological Field-Effect Transistors (BioFET): structure and working principle
- Surface charge modulation and threshold voltage shift
- Screening effects and Debye length limitations
- Scaling laws and signal-to-noise considerations
- Analytical models of sensor response

Module 4: Low-Dimensional Systems and Quantum Effects (8 Hours)

- Density of states in 3D, 2D, 1D, and 0D systems
- Quantum confinement and size effects
- Tunneling phenomena and quantum transport (basic concepts)
- Quantum capacitance
- Role of 2D materials (graphene, MoS_2, etc.) in sensing applications

Module 5: Physics of Flexible and Soft Electronics (8 Hours)

- Mechanics of flexible systems: stress, strain, bending radius
- Strain-induced modulation of electronic properties
- Organic semiconductors and disordered systems
- Percolation theory in conducting networks
- Charge transport in polymer and flexible electronic materials
- Coupling between mechanical deformation and conductivity
- Self-heling polymer devices

Module 6: Neuromorphic Devices for Smart Robotics, Prosthetic (8 Hours)

- Biological Synaptic system, Concept of Neuromorphic devices: Resistive Switching Devices (ReRAM / Memristors), Phase Change Devices, Ferroelectric Synaptic Devices, Spintronic Synaptic Device, Synaptic Transistor, Optoelectronic / Photo-Synaptic Devices
- Non-linear I–V characteristics and hysteresis behavior
- Microscopic mechanisms: ionic migration, vacancy dynamics

- Filamentary and interface-type switching
- Synaptic functionalities: Short-term and long-term plasticity, spike rate dependent plasticity, spike number dependent plasticity.
- Reliability and endurance under electrical/mechanical stress
- Energy-efficient performance metrics for electronic devices

Module 7: Energy Devics (10 Hours)

- Fundamentals of energy conversion: renewable vs non-renewable sources, efficiency, and power density
- Working principle of solar cells and types (Si, thin-film, perovskite)
- I–V characteristics and efficiency of photovoltaic devices
- Energy storage devices: lithium-ion batteries and supercapacitors
- Energy density vs power density and charge–discharge characteristics
- Basics of fuel cells and hydrogen as a clean energy source
- Thermoelectric (Seebeck effect), piezoelectric energy harvesting, pyroelectric energy harvesting, triboelectric energy harvesting, Types of nanogenerators.
- Applications in electric vehicles, wearable devices, and sustainable energy systems

Reference Books:

1. S. M. Sze & Kwok K. Ng, Physics of Semiconductor Devices, Wiley
2. Supriyo Datta, Electronic Transport in Mesoscopic Systems, Cambridge
3. Janata & Josowicz, Principles of Chemical Sensors
4. Takao Someya & John Rogers, Flexible Electronics
5. Ashcroft & Mermin, Solid State Physics
6. Waser et al., Redox-Based Resistive Switching Memories

Paper Name: ***ASIC and FPGA design and applications***
Paper Code: PHY458
Credit: 4
L T P – 3-0-1

Course Objectives:

1. Understand the fundamental concepts of Application-Specific Integrated Circuits (ASICs) and Field-Programmable Gate Arrays (FPGAs).
2. Compare and contrast ASIC and FPGA technologies in terms of design flexibility, cost, performance, and power consumption for different applications.
3. Apply Hardware Description Languages (HDLs) like VHDL or Verilog for digital circuit design, simulation, and synthesis targeted for ASIC and FPGA platforms.
4. Analyze and implement combinational and sequential logic circuits using modern design tools for synthesis and verification.
5. Explore the design flow of ASICs, including logic synthesis, floor planning, placement and routing, and timing analysis.

Course description:

This course provides a comprehensive introduction to the design and implementation of digital systems using Application-Specific Integrated Circuits (ASICs) and Field-Programmable Gate Arrays (FPGAs). Students will learn the architectural differences, design methodologies, and practical trade-offs between ASIC and FPGA technologies. The course covers the complete digital design flow, including modeling with Hardware Description Languages (HDLs) such as VHDL or Verilog, simulation, synthesis, and implementation. Real-world applications in embedded systems, signal processing, and high-performance computing will be examined to illustrate the strengths of ASIC and FPGA technologies in industry.

Course Outcomes (COs):

After completing this course, students will be able to:

CO1: **Explain** the architecture, functionality, and design methodologies of ASICs and FPGAs.

CO2: **Develop** digital circuits using Hardware Description Languages (HDLs) such as VHDL or Verilog for synthesis on ASIC and FPGA platforms.

CO3: **Analyze** and design combinational and sequential logic blocks including FSMs counters, ALUs, and memory interfaces.

CO4: **Evaluate** the performance, area, and power trade-offs between ASIC and FPGA implementations for various applications.

CO5: **Apply** industry-standard tools for simulation, synthesis, placement & routing, and timing analysis in the ASIC and FPGA design flow.

CO6: **Design** prototype digital subsystems or embedded applications using FPGA development boards.

Course Content

Module I: Introduction to ASICs and FPGAs

10 Lectures

Basic concepts of digital ICs, Types of ICs: SSI, MSI, LSI, VLSI, Introduction to ASIC: full-custom, semi-custom (standard cell, gate array), FPGA: architecture and structure (LUTs, CLBs, I/O blocks, routing), Comparison of ASICs and FPGAs (cost, speed, flexibility)

Module II: Hardware Description Languages (HDL)

10 lectures

Overview of Verilog or VHDL syntax and semantics, Modules, ports, data types, Combinational logic coding, Sequential logic coding (always blocks, clocked processes), Writing simple test benches

Module III: Digital Design Using HDL

10 lectures

Design of basic combinational blocks: MUX, DEMUX, Encoder, Decoder, Sequential blocks: Flip-flops, Counters, Shift Registers, Finite State Machines (FSMs): Mealy and Moore, Parameterized and hierarchical design concepts, Simulation and verification basics

Module IV: FPGA Architecture and Design Flow

10 lectures

Internal structure of an FPGA, Design flow: design entry → synthesis → implementation → bit stream, Tools overview (Vivado, Quartus), Basic constraints (timing, pin assignment – concept only), Configuration and programming of FPGAs

Module V: ASIC Design Basics

10 lectures

ASIC design flow: RTL → gate-level → layout, Logic synthesis concepts, Basics of placement, routing, and timing, Concept of design for testability (DFT)

List of Experiments

1. **Experiment 1**: Simple FPGA-based applications: traffic light controller, digital clock
2. **Experiment 2**: ASIC in real-world products: microcontrollers, signal processors
3. **Experiment 3**: Overview of applications in communication, automotive, and consumer electronics. Emerging areas: IoT, AI hardware, embedded systems

Reference Books:

1. *FPGA-Based System Design*, **Wayne Wolf**, Pearson
2. *Application-Specific Integrated Circuits*, **M.J. Smith,** Addison-Wesley
3. *Fundamentals of Digital Logic with Verilog Design,* **Brown & Vranesic, WordPress**
4. *Verilog HDL: A Guide to Digital Design and Synthesis,* **Samir Palnitkar, SunSoft Press**

Paper Name: ***Analog and Digital Electronics***
Paper Code: **PHY459**
Credit: **4**
LTP: **4-0-0**

Course Objectives

1. To provide students with a thorough understanding of active circuits, focusing on transistor amplifiers and design considerations.
2. To explore the physical mechanisms of semiconductor materials and their implications in electronic devices.
3. To equip students with knowledge of various semiconductor devices, their characteristics, and applications in modern electronics.
4. To develop practical skills in analog circuit design and logic gate minimization techniques.
5. To introduce the architecture and functioning of microprocessors, specifically the Intel 8085 and 8086, alongside their assembly language programming.

Course Outcomes

CO1: Recall and describe the principles of semiconductor physics, electronic devices, logic gates, and microprocessor architecture.

CO2: Explain the working mechanisms and characteristics of active circuits, analog circuits, and combinational and sequential circuits, connecting them to real-world applications.

CO3: Design and implement electronic circuits, such as amplifiers, multivibrators, counters, and shift registers, to perform specific functions using Boolean minimization and microprocessor instructions.

CO4:Analyzethe performance and behavior of semiconductor devices, combinational circuits, and microprocessor-based systems, identifying critical parameters and operational limitations.

CO5: Evaluate the efficiency and reliability of programmable logic devices, semiconductor memories, and digital systems in various computational and electronic applications.

Catalogue Description

The course aims to demonstrate the idea of the fundamental aspects of Analog and Digital Electronics. It will help to build the knowledge about the semiconductor physics and its applications in various semiconductor devices as well as microprocessors and microcontrollers.

Course Content

Module 1: Active Circuits:

6 Lectures

Transistor amplifiers; Basic design consideration; Class A power amplifier, Coupled Class A power amplifier, Coupled Amplifier, Push-pull amplifier, Class B and Class C tuned power amplifier. High frequency effects, resonance amplifier, feedback and distortion in amplifiers

Module 2: Physical Mechanism and Semiconductor Devices

10 Lectures

Energy Band consideration in solids in relation to semiconductors, Direct and Indirect bands in semiconductor, Carrier mobility in semiconductors, Electron and Hole conductivity in semiconductors, Carrier Trapping and recombination/ generation in semiconductors, Shockley Read theory of recombination, Switching Electronic Devices, Metal/Semiconductor Junction or (Abrupt P-N Junction), Current-voltage characteristics, C-V Measurements, Estimation of Barrier Height and carrier concentration from C-V characteristics, Surface/Interface States, Role of interface States in Junction Diodes. Field Effect devices, C-V characteristic of MIS diodes (Frequency dependence), Estimation of Interface Trapped charges by capacitance conductance, method CCD (Charge Coupled Devices), MESFET, MOSFET.

Module 3: Special Device:

6 lectures

Tunnel diode: I-V characteristics, negative voltage region. Uni- junction transistor (UJT), Application as a relaxation oscillator. Silicon Controlled rectifier (SCR, Thyristor) characteristics and applications. Photonic Devices: LED and LASER, Photo detectors, Solar-cells. ATT device, Power diodes. Power transistors. GTOs and IGBTs

Module 4: Analog Circuits:

4 lectures

Comparators, Multivibrators, Waveform generators: square wave, triangle wave and pulse generators

Module 5: Minimization Techniques and Logic Gates:

6 lectures

Boolean postulates and laws, Principle of Duality, Minimization of Boolean expressions, 8-4-2-1 BCD code, Minterm, Maxterm, Karnaugh map Minimization, Quine - McCluskey method of minimization. Multi-level gate implementations, Multi output gate implementations, TTL and CMOS Logic and their characteristics, Tristate gates

Module 6: Combinational Circuits:

6 lectures

Design Procedure of Adder and Subtractor: Parallel Binary adder, Look Ahead carry adder, BCD adder. Other Combinational Circuits: Parity Bit Generator/Checker, Magnitude Comparator, Code Converters, Encoder, Decoder, Multiplexer, De-Multiplexer.

Module 7: Sequential Circuits:

8 Lrectures

Latches and Flip-Flops: Gated S-R Latch, D Latch, J-K Latch, T Latch, Edge Triggered S-R Flip Flop, Edge Triggered D Flip Flop, Edge Triggered J-K Flip Flop, Edge Triggered T Flip-Flops, Master - Slave Flip-Flops, Direct Preset and Clear Input.
Counters and Shift Registers: Design of asynchronous counters, Effects of propagation delay in Ripple counters, Design of synchronous counters, Ring counter, Johnson counter, Pulse train generators using counter, Design of Sequence Generators, Shift registers: SISO, SIPO, PISO, PIPO, Universal Shift register

Module 8: Semiconductor Memory and Programmable Logic:

6 lectures

Classification of memories: Programmable Read Only Memory, Erasable Programmable Read Only Memory, Electrically EPROM, EAPROM, RAM – RAM organization, Static RAM Cell, Bipolar RAM cell, MOSFET RAM cell, Dynamic RAM cell, Programmable Logic Devices, Programmable Logic Array (PLA), Programmable Array Logic (PAL), Field Programmable Gate Arrays (FPGA), Implementation of combinational logic circuits using ROM, PLA, PAL

Module 9: Intel 8085 and 8086 Microprocessor Architecture:

6 lectures

Main features of 8085 and 8086. Block diagram. Components. Pin-out diagram. Buses. Registers. ALU. Memory. Stack memory. Timing and Control circuitry. Timing states. Instruction cycle, Timing diagram of MOV and MVI. Introduction to Assembly Language: 1 byte, 2 byte and 3 byte instructions.

Reference Books:

1. Electronic Principles, Malvino and Bates
2. Analog Electronics, J B Gupta
3. Integrated Electronics, Millman, Halkias
4. Fundamentals of Digital Circuits" by A. Anand Kumar (PHI)
5. Digital Electronics And Logic Design" by M.Mano (PHI) 6.

6. Digital Circuits and Design (Fourth Edition-2012) by S. Salivahanan and S. Arivazhagan, Vikas Publishing House
7. Digital Circuits and Logic Design – LEE, PHI
8. Digital Fundamentals: Floyd and Jain: Pearson Education

Paper Name: ***Electronics for Renewable Energy Systems***
Paper Code: PHY460
L T P – 4-0-0

Course Objectives:

1. To understand the fundamentals of renewable energy sources.
2. To explore the role of power electronics in renewable energy systems
3. To analyze power conversion circuits (DC-DC converters, DC-AC inverters, and AC-DC rectifiers etc.).
4. To realize the grid integration techniques.
5. To promote sustainable engineering practices.

Course Description:

This course introduces the application of electronic systems in the field of renewable energy, focusing on the generation, conversion, control, and integration of energy from sources such as solar and wind. Students will explore power electronic devices, converter topologies, and control methods essential for interfacing renewable sources with loads and the grid. Key topics include photovoltaic system electronics, wind energy conversion electronics, battery energy storage systems, and grid integration strategies.

Course Outcomes:

By the end of this course, students will be able to:

CO1: Understand the fundamentals of renewable energy sources

CO2: Analyze power electronic converters used in renewable energy systems

CO3: Design basic power electronic circuits (e.g. MPPT controllers, inverters) for renewable applications

CO4: Evaluate performance and efficiency of renewable energy systems (e.g. PV, wind etc.)

CO5: Apply relevant standards and safety practices like electrical safety codes and national/international standards (e.g., IEEE, IEC) in renewable energy electronics.

Course Content

Module I: Introduction to Renewable Energy Systems

Introduction to renewable energy sources, Importance of renewable energy in modern power systems Solar, wind, biomass, and hybrid systems: basic structure Role of electronics in energy generation, conversion, and management

Module II: Power Electronic Devices and Converters

Introduction to power semiconductor devices: Diodes, MOSFETs, IGBTs, Rectifiers, inverters, choppers, and basic converter topologies, Efficiency, switching behavior, and thermal issues (introductory level), Principle of conversion of solar radiation into heat, Collectors used for solar thermal conversion

Module III: Solar Photovoltaic (PV) Electronics

Basics of PV cell operation and I-V characteristics, MPPT techniques, Solar charge controllers: PWM vs MPPT, Standalone vs grid-connected PV systems, Solar inverters (overview of types and function).

Module IV: Wind Energy Conversion and Control

Basics of wind energy generation: mechanical to electrical, Wind turbine generator types (Squirrel Cage, DFIG, PMSG – brief overview), AC-DC-AC conversion for wind systems, Wind energy system control and protection basics.

Module V: Battery Energy Storage and Electronics

Battery types: Lead-acid, Li-ion, Charging/discharging principles, Simple BMS (Battery Management System) concepts, Introduction to DC-DC bidirectional converters for storage

Module VI: Grid Integration and Power Quality

Grid-connected vs off-grid renewable systems, Synchronization and basic PLL concept, Inverter interface with the grid, Power quality basics: voltage sag, harmonic content, islanding

Module VII: Trends and Applications

Smart inverters and IoT in energy systems, Introduction to hybrid renewable systems, Case studies: Solar home systems, wind-solar hybrid mini-grid

Reference Books:

1. *Non-Conventional Energy Resources* **B.H. Khan**
2. *Power Electronics: Circuits, Devices, and Applications,* **M.H. Rashid** –
3. *Solar Photovoltaics: Fundamentals, Technologies, and Applications* **C.S. Solanki**
4. *Power Electronics: Converters, Applications, and Design* **Ned Mohan**
5. *Energy- Fundamentals, design, modeling & applications*; **G.N. Tiwari,** Solar, Narosa Pub., 2005.

Paper Name: ***Quantum Field Theory***
Paper Code: **PHY505**
Credit: **4**
LTP: **4-0-0**

Course Objectives:
By the end of the course, students will be able to:

1. **Formulate classical field theory** using the action principle, derive Euler–Lagrange equations for fields, and apply Noether's theorem to obtain conserved currents associated with continuous symmetries.

2. **Quantize free scalar and spinor fields** using canonical methods, construct field operators, derive commutation and anticommutation relations, and compute two-point correlation functions and propagators (retarded, advanced, and Feynman).

3. **Analyse spacetime and discrete symmetries** in relativistic quantum field theory, including Lorentz invariance, C, P, T transformations, and understand the significance of CPT invariance and the spin–statistics connection.

4. **Quantize the electromagnetic field** in the presence of gauge redundancy, implement gauge fixing (Coulomb gauge and Gupta–Bleuler formalism), construct photon states, and derive the covariant photon propagator.

5. **Apply covariant perturbation theory** in the interaction picture, use Wick's theorem to evaluate time-ordered products, construct the S-matrix, and compute lowest-order scattering amplitudes using Feynman diagrams for scalar field interactions (e.g., ϕ^4 theory).

Course Description:
This Discipline-specific elective course introduces M.Sc. Physics students to the foundations of Quantum Field Theory, the theoretical framework unifying quantum mechanics and special relativity. Beginning with classical field theory and the action principle, the course develops the canonical quantization of scalar and spinor fields, along with correlation functions and propagators. It examines spacetime and discrete symmetries, including Lorentz and CPT invariance. A dedicated module covers gauge invariance and the quantization of the electromagnetic field, including gauge fixing and photon propagators. The course concludes with the interaction picture, covariant perturbation theory, Wick's theorem, and Feynman diagrams for simple interacting field theories. This course prepares students for advanced study in high energy and theoretical physics.

Course Outcomes:

CO1: Formulate the theoretical framework of classical and relativistic field theory, including the action principle, symmetry principles, and conservation laws governing physical systems.

CO2: Apply canonical quantization methods to relativistic fields and **construct** field operators, commutation or anticommutation relations, and Green's functions relevant to quantum field theory.

CO3: Analyse the role of spacetime, internal, and discrete symmetries in quantum field theory and **evaluate** their physical consequences, including invariance principles and conservation laws.

CO4: Examine the structure of gauge theories by implementing gauge invariance and appropriate quantization procedures, and **interpret** the physical content of gauge fields and their propagators.

CO5: Develop and apply perturbative methods in quantum field theory, including the interaction picture and S-matrix formalism, to **compute** and **interpret** transition amplitudes for interacting fields.

Course Content

Module 1: Preliminaries (6 Hours)

Units and conventions, Motivation, Canonical fields as generalized coordinates, Action Principle, Euler-Lagrange equations for fields, Noether's theorem and conserved currents.

Module 2: Free Scalar Fields (10 Hours)

Canonical quantization of scalar and complex scalar fields, Two-point Correlation Functions, Green Functions: Retarded, advanced, Feynman propagator; Physical interpretation of propagators.

Module 3: Spinor Fields (8 Hours)

Dirac Equation and Field Quantization, Spinor Solutions, Anticommutation Relations, Feynman Propagator for Dirac Fields

Module 4: Symmetries and Invariances (7 Hours)

Lorentz invariance of free field theory, C, P, T and CPT transformations, CPT and spin statistics theorems.

Module 5: Quantization of the Electromagnetic Field (10 Hours)

Classical Electromagnetic Field as a Gauge Theory, Difficulties in Canonical Quantization, Gauge Fixing and Quantization: Coulomb gauge quantization, Gupta–Bleuler formalism, Photon States and Propagator

Module 6: Introduction to Interactions (10 Hours)

Interaction picture, Covariant perturbation theory, Wick's theorem, S-matrix, Feynman diagrams for Scalar Field Interactions (e.g. ϕ^4).

References:

1. A Lahiri and P B Pal, A first book of Quantum Field theory, Narosa, 2nd Edition, 2005.
2. L H Ryder, Quantum Field Theory, Cambridge University Press, 2nd Edition, 1996.
3. Itzykson and Zuber, Quantum field theory, Dover Publications Inc, 2006.
4. M.E. Peskin and D.V. Schroeder, An introduction to quantum field theory, Perseus Books, 1995.
5. J.D. Bjorken and S.D. Drell, Relativistic Quantum Fields, McGraw-Hill College, 1st Edition, 1965.
6. F. Mandl and G. Shaw, Quantum Field Theory, Willey-Blackwell, 2nd Edition, 2010.
7. P. Ramond, Field Theory: A Modern Primer, Benjamin/Cummings Pub. Co./Sarat Book House, 2007.

Paper Name: ***Many-electron systems and Material Science***
Paper Code: **PHY506**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce the quantum mechanical treatment of many-electron systems using second quantization formalism.

2. To apply mean-field and perturbative approaches, including the Hartree-Fock method and Feynman diagram techniques.

3. To explore the symmetry, structure, and defects in crystalline solids and their implications on material properties.

4. To understand electronic properties, semiconductor behavior, and phase transitions in various classes of materials.

5. To expose students to synthesis techniques and experimental methods for material characterization, with emphasis on nanomaterials and smart alloys.

Course Description:

This course offers an in-depth understanding of many-electron systems, quantum mechanical frameworks, and the physical principles governing the behavior of real materials. Starting from second quantization and Hartree-Fock methods, the course extends to advanced perturbative techniques and models for electron correlation. It then covers the structural, electronic, and thermal properties of crystalline and amorphous materials, with a strong emphasis on symmetry and defects. The final module introduces synthesis and characterization methods for modern materials, including nanostructures, alloys, and smart materials. The course is designed to prepare students for advanced research in condensed matter and materials science.

Course Outcomes:

CO1: **Recall and describe** key quantum concepts, structural features, and classification of materials.

CO2: **Explain and interpret** quantum many-body methods, symmetry principles, and electronic band structures.

CO3: **Apply** Hartree-Fock formalism and semiconductor theory to calculate material properties.

CO4: **Analyze** crystal symmetries, defect structures, phase transitions, and thermodynamic behavior in solids.

CO5: **Evaluate** the theoretical principles behind material synthesis techniques and characterization methods, and critically assess their applicability to different material systems.

Course Content:

Module I

[10 lecture hours]

Fundamentals of many-electron systems and Second quantization

Schrodinger equation for a many-electron system, Matrix elements of non-interacting and interacting parts, and applicability of perturbation theory to solve an interacting many-electron problem. Creation and annihilation operator, occupation no representation, (anti)-commutation relations, Vacuum state, Matrix elements of the non-interacting and interacting parts of a many electron Hamiltonian for one, two and many electron systems.

Module II

[10 lecture hours]

Hartree-Fock method

Hartree-Fock formulation in continuum, application of variational method, Calculation of ground state energy of an interacting electron gas, single electron H-F equation, Koopmans's theorem, Calculation of specific heat, correlation energies etc. Hubbard Hamiltonian, Mott transition, Introduction to Hubbard model, extended Hubbard model, Mott insulators, t-J model, magnetic impurities, Kondo effect and related problems

Diagrammatic perturbation Theory

Recapitulations of Schrodinger, Heisenberg and interaction picture, Adiabatic hypothesis, Feynman graphs: First order and Higher order, linked and unlinked graph, linked graph theorem, Green's Function and one-electron Schrodinger equation Green's function operator, Density of states of a system subjected to small perturbation

(The above unit is only for advanced learners)

Module III

[3 lecture hours]

Overview of Materials

Structure and bonding in solids, crystalline solids: (metals/insulator/semiconductor).Amorphous materials: Glasses and their application, luminescent and optoelectronic materials.

[10 lecture hours]

Study of Symmetry in Crystalline Structure

Lattice Translation vectors, Basis and crystal structure, Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell. Symmetry operations (discussion on Translation, rotation, reflection, inversion operation) and classification of 2D and 3D Bravais lattices, point group and space group (in depth discussion). Symmetry and degeneracy, crystal field splitting; Kramer's degeneracy, Quasicrystals: general idea, Penrose tiling, Frank-Casper phase in metallic glass.

[5 lecture hours]

Study of Defects in Crystalline Structure

Idea of closed packed structure, lattice constant/cell volume, Imperfection in solids, Classification of defects: linear defects, slip and plastic deformation, Planar defects, Volume defects, Formation of colourcentres by irradiating a single crystalline material, Dislocations: Shear Strength of single crystal, Burger vectors, Dislocation densities, Slip, A brief discussion on hardness materials/alloys. A brief discussion on Hume-Rothery rules, Bragg-Williams theory and order-disorder phenomena.

Module IV

Properties of Materials

[5 lecture hours]

Band structure: Band model of Intrinsic semiconductor and insulators, Law of mass action, Band model of Extrinsic semiconductor: Calculation of electron and hole concentration, Measurement of band gap, the infrared absorption in semiconductor, Semiconductor junction and devices p-n junction, Junction rectifier, The junction transistor, Tunnel diode, Photodiode.

[5 lecture hours]

Phase transition in materials:

Thermodynamics and phase diagrams, statistical theories of phase transitions, critical phenomena, calculation of critical exponents for van-der Waals gas and ferromagnets, Diffusion in solids, variation of diffusion constant with temperature.

Module V-

[10 lecture hours]

Synthesis and Characterization of Materials

Introduction to Nano-materials: Size dependent properties of nanomaterials. Thermodynamics of phase transition-nucleation and growth. Fabrication process of materials-Top-down and bottom up approaches of nanomaterial synthesis. Solution growth techniques Thermal evaporation/PLD/CVD, Sol-gel processing, Electrodeposition, Alloys: synthesis and study of Half and Full Heusler alloys, shape memory effects in alloys, smart materials Phase identification through X-ray diffraction (XRD), Study of microstructure-electron microscopy: Scanning electron microscopy (SEM), Transmission electron microscopy (TEM). Introduction to Scanning Probe Microscopy (SPM): Atomic Force Microscopy (AFM) and Scanning Tunnelling Microscopy (STM). Characterization of defects by Positron annihilation lifetime spectroscopy.

References:

1. Quantum Many-Particle Systems; Negele, J. W., & Orland, H. (1998)
2. Quantum Theory of Many-Particle Systems; Fetter, A. L., & Walecka, J. D. (1971)
3. Solid State Physics; Ashcroft, N. W., & Mermin, N. D. (1976)
4. Interacting Electrons and Quantum Magnetism; Auerbach, A. (1994)
5. Materials Characterisation Techniques; Zhang, S., Li, L., & Kumar, (2008)

Paper Name: ***Biomedical Instrumentation and MEMS Technology***
Paper Code: **PHY507**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

By the end of the course, students will be able to:

1. Understand the anatomical and physiological basis of various human body systems.
2. Learn the physics and engineering behind diagnostic and therapeutic medical instrumentation.
3. Explore the integration of MEMS in biomedical signal sensing and microfluidics.
4. Analyze design challenges, safety, and ethical issues in medical instrumentation.
5. Introduce students to the design and functioning of prosthetics and advanced biomedical systems.
6. Foster critical thinking in applying MEMS and instrumentation knowledge to solve biomedical problems.

Course Description:

This course integrates human anatomy and physiology with principles of biomedical instrumentation and introduces Micro-Electro-Mechanical Systems (MEMS) in the healthcare context. It covers physiological systems and bio-signals, diagnostic and therapeutic instrumentation, and the role of MEMS-based sensors, actuators, and microsystems in modern biomedical engineering. Students will gain an understanding of biological systems and signals, their measurement using various instruments, and the role of MEMS and microsensors in advancing healthcare technology. Emphasis is placed on diagnostic and therapeutic applications, safety, and innovation in biomedical engineering.The course aims to build interdisciplinary competence by combining foundational life science knowledge with applied instrumentation and technology.

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Course Outcomes:

CO1: Describe the anatomical organization and physiological processes of major body systems including cardiovascular, respiratory, nervous, and musculoskeletal systems.

CO2: Explain the origin, measurement, and interpretation of biomedical signals like ECG, EEG, and EMG, along with their instrumentation systems.

CO3: Classify and analyze various sensors and transducers used in biomedical systems.

CO4: Evaluate diagnostic and therapeutic medical instruments, including those based on IoT.

CO5: Apply MEMS principles in biosensing, drug delivery, and smart prosthetics, and other applications to address real-world medical needs.

CO6: Analyze the working principles and clinical applications of advanced biomedical systems

Course Content

Module 1: Human Physiology and Anatomy Overview *(10 hours)*

Organization of human body, cellular structure, tissues. Systems overview: cardiovascular, respiratory, musculoskeletal, nervous. Physiology of digestion, excretion, and sensory organs. Electrical excitability of cells, muscle contraction, neural conduction.

Module 2: Biomedical Signals and Instrumentation Systems *(10 hours)*

Origin of ECG, EEG, EMG, EOG, ERG signals. Electrode types, interface, and placement. Signal amplification, filtering, and digital storage. PC-based medical instrumentation and telehealth systems. Sensors and Transducers in Biomedical Systems: Basic concepts, classification, static and dynamic characteristics. Biomedical-specific sensors: oxygen, glucose, EMG/EEG/ECG electrodes, tactile and force sensors. Signal conditioning and interface circuits

Module 3: Diagnostic and Therapeutic Instrumentation *(10 hours)*

Diagnostic tools: oximeters, spirometers, blood flowmeters (EM, Doppler, NMR). Therapeutic instruments: pacemakers, defibrillators, diathermy, ventilators, anesthesia systems. Performance metrics: efficiency, accuracy, clinical safety. Functional aspects and design consideration. IoT and point of care technology.

Module 4: Advanced Biomedical Systems and Prosthetics *(15 Hours)*

Haemodialysis, ultrasonic imaging, Doppler and tomography. Prosthetics: types, neural interfaces, smart prostheses. AI-enabled prosthetics and rehabilitation devices. Biomedical device design challenges and ethical issues. Neuroprosthetics & Brain-Computer Interfaces (BCIs). Advanced robotic limbs (upper and lower extremity) with multiple degrees of freedom. Implantable Prosthetics & Devices. 3D bioprinting techniques.

Module 5: MEMS Technology in Biomedical Applications *(15 Hours)*

Basics of MEMS: fabrication, materials, design. MEMS sensors and actuators: pressure, flow, chemical, and biosensors. Microfluidics for lab-on-chip diagnostics and drug delivery. MEMS-based implantable and wearable devices. MEMS integration in neural prostheses and miniaturized diagnostic systems.

References:

1. John G. Webster, *Medical Instrumentation: Application and Design*, 4th Edition, Wiley, 2009.
2. R.S. Khandpur, *Handbook of Biomedical Instrumentation*, 3rd Edition, Tata McGraw-Hill, 2014.
3. Willis J. Tompkins (Editor), *Biomedical Digital Signal Processing: C-Language Examples and Laboratory Experiments for ECG and EMG*, Prentice-Hall, 1993.
4. Gabor T.A. Kovacs, *Micromachined Transducers Sourcebook*, McGraw-Hill, 1998.
5. Gerard J. Tortora and Bryan H. Derrickson, *Principles of Anatomy and Physiology*, 15th Edition, Wiley, 2017.
6. Subhas Chandra Mukhopadhyay (Editor), *Wearable and Implantable Medical Devices*, Springer, 2015.

Paper Name: ***Astrophysics and Cosmology I***
Paper Code: **PHY508**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

The objectives of this course are to:

1. Introduce students to the basic concepts, tools, and observational foundations of modern astrophysics and cosmology.
2. Provide an understanding of the methods of astronomical measurement and the structure and evolution of the Universe.
3. Develop mathematical proficiency in the relativistic framework and tensor calculus required for cosmology.
4. Explore the structure and evolution of stars and the radiative processes governing astrophysical phenomena.
5. Build a solid conceptual and observational foundation for advanced study in cosmology and related research.

Course Description:

This course provides a comprehensive introduction to the key concepts of modern astrophysics and cosmology. It begins with an overview of the Universe and the observational techniques used to measure astronomical phenomena. A mathematical primer equips students with the necessary tools in special relativity and general relativistic formalism for cosmological applications. The course then covers the physics of stellar structure and evolution, along with the radiative processes that govern energy transport in astrophysical systems. The final module introduces the Standard Model of Cosmology (ΛCDM), presenting the theoretical framework, observational evidence, and open questions about the Universe.

Course Outcomes:

CO1: **Develop** a rigorous understanding of tensor calculus and relativistic frameworks, including spacetime geometry, curvature tensors, and Einstein's field equations.

CO2: **Apply** the mathematical tools of special and general relativity, including tensor calculus, to **formulate** fundamental equations governing astrophysical and cosmological systems.

CO3: **Utilize** observational techniques and astronomical data analysis, including photometry, distance ladders, and telescope-based measurements to interpret cosmic structures.

CO4: **Evaluate** stellar structure and evolution using hydrodynamic and thermodynamic principles, including virial theorem, polytropic models.

CO5: **Analyze** the standard cosmological model through Friedmann dynamics, cosmological distances, and observational probes such as CMB, supernovae, and large-scale structure.

Course Content

Module 1: Tensor Calculus and Relativity *(14 Hours)*

Covariant & contravariant tensors, index notation; Metric tensor: Line element, raising/lowering indices; Affine connection; Parallel Transport; Christoffel symbols and covariant derivatives; Geodesics and geodesic equation; Manifolds and curvature; Riemann curvature tensor, Ricci tensor, Ricci scalar, Einstein tensor.

Special Theory of Relativity (STR): Invariance of Spacetime interval, Einstein's postulates, Lorentz transformations, Time dilation, length contraction, Simultaneity, Energy-Momentum Tensor, Minkowski space and causality.

General Theory of Relativity (GTR): Postulates and Einstein field equations, Einstein-Hilbert action.

Module 2s: Measurement of Astronomical Data & Overview of the Universe *(10 Hours)*

Astronomical Coordinate Systems: Celestial sphere, right ascension/declination, galactic/ecliptic coordinates; Photometry & Magnitudes: Apparent vs absolute magnitude, Color indices, photometric systems; Distance Measurement Techniques: Parallax, Cepheid variables, Type Ia supernovae, Tully-Fisher relation, redshift-distance relations;

Telescopes & Observatories: Optical, radio, X-ray, IR, gamma-ray observatories, Ground-based vs space-based (HST, JWST, LSST, etc.);

Stellar classification: Henry-Draper and modern M-K Classification schemes, H-R Diagram, Empirical mass- luminosity relation.

Qualitative description of the large-scale structure of the universe: (i) Hierarchy: planets, stars, galaxies, clusters, filaments, voids (ii) Observable universe and cosmic horizon; Timeline of the Universe.

Module 3: Stellar Hydrodynamics *(12 Hours)*

Virial theorem, Hydrostatic equilibrium, Polytropic Stellar Model – Lane Emden Equation and its solution, Jeans Criterion, Tolman-Oppenheimer-Volkoff equation evolution of stars during and after their location on the main sequence.

Module 4: Standard model of Cosmology *(13 Hours)*

Cosmological Principle, Geometry of the Universe: FLRW metric; Friedmann equations and cosmic dynamics; Scale factor evolution in radiation, matter and dark energy-dominated epochs, Critical density and cosmological parameters, Basics of ΛCDM model, large-scale structure, qualitative introduction to CMB constraints, Cosmological distances: comoving, proper, angular diameter, luminosity distances, Cosmic horizons, Fate of the Universe and open questions.

References:

1. M. L Kutner, *Astronomy: A Physical Perspective*, Cambridge University Press, 2003.
2. B. W. Carrol and D. A. Ostlie, *An Introduction to Modern Astrophysics*, Pearson, 2006.
3. Arnab Rai Choudhuri, *Astrophysics for Physicists*, Cambridge University Press, 2010.
4. T. Padmanabhan, *Theoretical Astrophysics: Astrophysical Processes (Volume I)*, Cambridge University Press, 2010.
5. T. Padmanabhan, *Theoretical Astrophysics: Stars and Stellar systems (Volume II)*, Cambridge University Press, 2010.
6. C. J. Hansen, S. D. Kawaler and V. Trimble, *Stellar Interiors: Physics Principles, Structure and Evolution*, Springer Verlag, 2nd edition, 2004.
7. Dina Prialnik, *An Introduction to the Theory of Stellar Structure and Evolution*, Cambridge University Press, 2nd edition, 2009.
8. George B. Rybicki and Alan P. Lightman, *Radiative Processes In Astrophysics,* WILEY VCH, 1st edition, 1985.
9. Scott Dodelson, *Modern Cosmology*, Academic Press Inc, 2nd edition, 2020.
10. Barbara Ryden, *Introduction to Cosmology*, Cambridge University Press, 2nd edition, 2016.

Paper Name: ***Statistical and Quantum Optics***
Paper Code: **PHY509**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Introduce students to Mathematica and its applications in solving complex problems in physics, enhancing their computational skills.
2. Develop students' understanding of quantum transport phenomena, focusing on electron and spin transmission in quantum systems.
3. Facilitate hands-on experience with computational simulations using Mathematica, Python, or MATLAB to analyze various quantum mechanical problems.
4. Enhance students' ability to visualize complex data through various plotting techniques, improving their interpretative and analytical skills.

Course Outcomes:

CO1: Analyze probability distributions and statistical functions including moment generating and characteristic functions, and apply the central limit theorem and concepts of random processes in physical systems.

CO2: Explain the quantization of electromagnetic fields and examine vacuum fluctuations and number states within the framework of linear response theory.

CO3: Evaluate spatial and temporal coherence using the coherence function, and interpret polarization states and interference laws using coherent mode representations.

CO4: Apply the van Cittert-Zernike theorem and Mandel's photon counting formula to real interferometric experiments, and analyze the optical response of matter using Lorentz-Drude and Kramers-Kronig models.

CO5: Investigate light–matter interactions at the nanoscale and design optical structures such as photonic crystals and metamaterials to control emission and propagation characteristics.

Catalogue Description:

This course first provides treatment of optical phenomena by going beyond Maxwell equations to explicitly treat generation/propagation/detection of light as statistical random processes. Classical and quantum treatment of coherence properties of optical fields and their applications are discussed.

Course Content:

Module-I

[8 lecture hours]

Unit 1

Probability distributions, moment generating function and characteristic function, Gaussian distribution, central limit theorem, analytic signal representation

[10 lecture hours]

Unit 2

Random processes, correlations, stationarity, Wiener-Khintchine theorem, Linear Response Theory
Quantization of EM fields, number states, vacuum fluctuations

Module-II

[12 lecture hours]

Unit 3

Unified framework of coherence and polarization
Temporal and spatial coherence, coherence function, Law of interference (2 slit experiment), spectral interference law, degree of polarization, Coherent mode representation in space-frequency domain

Glauber-Sudarshan representation, test for no classicality, bunching and anti-bunching

Module-III

[10 lecture hours]

Unit 4

van Cittert Zernike theorem, Michelson stellar interferometer, Mandel's photon counting formula, Intensity correlations, Hanbury Brown Twiss effect , Quantum treatment of beam splitter and interferometers

[8 lecture hours]

Unit 5

Optical response of matter: Lorentz model, Lorentz-Drude model, Response theory, Kramers-Kronig relations, Speckle statistics and applications

Module IV **[12 lecture hours]**

Unit 6

Nano optics

Light emission and optical interactions in nanoscale environments- mutipole expansion, radiating electric dipole, spontaneous decay, delocalized excitations, Quantum emitters, dipole emission near planar interfaces, Near and far fields, Light in periodic structures: Photonic crystals and resonators, Surface plasmons, Evanesce waves, Meta materials.

Reference Books:

1) Statistical Optics, J. W. Goodman, Wiley–Interscience, 2000. (units 1, 2, and 3).
2) Optical Coherence and Quantum Optics, L. Mandel and E. Wolf, Cambridge University Press, 1995. (units 1, 2, and 3).
3) Introduction to theory of coherence and polarization of light, E. Wolf, Cambridge University Press, 2007. (units 2 and 3).
4) Modern Quantum Mechanics, J. J. Sakurai, Pearson Education, 2009. (unit 4).
5) Optical Coherence and Quantum Optics, L. Mandel and E. wolf, Cambridge University Press, 1995. (units 4, 5, and 6).
6) Quantum Optics, D. F. Walls and G. J. Milburn, Springer, 2007. (units 4, 5, and 6).
7) The quantum theory of light, R. Loudon, Oxford university press, 2000. (units 4, 5, and 6).
8) Principles of Nano-optics, L Novotny and B Hecht, Cambridge University Press (2006)
9) Introduction to Nanophotonics, S V Gaponenko, Cambridge University Press (2010)
10) Nanophotonics, H Rigneault(Ed.), ISTE (2006)
11) Principles of nanophotonics, Motoichi Ohtsu, CRC Press, (2008)
12) Fundamentals of Polarized light: A statistical Optics approach Christian Brosseau
13) Plasmonics: Fundamentals and Applications, by Stefan Maier
14) Fundamentals of Photonics by Bahaa E. A. Saleh

Paper Name: ***Nanoscience and Nanomaterial***
Paper Code: **PHY510**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce the fundamental principles of nanostructured materials and their application in electronics, photonics, and magnetism.
2. To explore the variation in electronic properties at the nanoscale and understand the quantum effects governing nanoscale materials and devices.
3. To understand molecular electronics and nanobiology, emphasizing the role of molecular devices and biological systems at the nanoscale.
4. To familiarize students with the practical applications of nanotechnology, focusing on nanomaterials for gas sensing and photonic devices.

Course Description:

This course provides an in-depth understanding of nanoscale materials and their electronic, optical, and magnetic properties. It covers the classification and unique behavior of 0D, 1D, and 2D nanostructures, along with synthesis techniques such as sol-gel processing, CVD, and hydrothermal methods. Characterization tools like XRD, SEM, TEM, AFM, STM, and positron annihilation spectroscopy are introduced for structural and defect analysis.
Students will explore electron behavior in nanostructures, including quantum confinement, Landauer resistance, Coulomb blockade, and applications in devices like single-electron transistors and resonant tunneling diodes. The course also introduces molecular electronics, covering charge transport mechanisms and single-molecule devices. Finally, it examines advanced electronic and photonic materials such as quantum well lasers, nanowire LEDs, and quantum dot detectors, bridging concepts with real-world nanotechnology applications.

Course Outcomes:

CO1: Define key concepts in nanostructured materials, molecular electronics, and nanobiology, including their applications in electronics, photonics, and sensors.
CO2: Explain the quantum effects and electronic behavior in nanostructures, including single-electron devices, Coulomb blockade, and resonant tunneling phenomena.
CO3: Apply theoretical models and experimental techniques to analyze nanoscale materials' electronic, photonic, and gas sensing properties.
CO4: Analyze the role of molecular and nanoscale fluctuations in biological systems and their implications for nanobiology and bio-nanotechnology.
CO5: Evaluate the performance of quantum-based devices, such as quantum dot lasers and quantum well photodetectors, to optimize their applications in photonics and sensing.

Course Content

Module 1: Nano-structured materials (*12 Hours*)

Introduction to Nanomaterials About size Scales, Forces at nanoscale, Nano-structuring, 0D, 1D, 2D nanostructures – size dependent properties of nanomaterials – Fraction of Surface Atoms, Optical properties of nanomaterials, Photonic application: 2D photonics for lasers, 3D photonics: band gap materials. Magnetic properties of nanomaterials: Super-Paramagnetism, Nano magnetic device: giant magneto resistance.

Module 2: Synthesis and Characterization of materials (*14 Hours*)

Thermodynamics of phase transition-nucleation and growth. Fabrication process of materials-Top-down and bottom up approaches of nanomaterial synthesis. the General Methods available for the Synthesis of Nanostrutures-Hydrothermal/solvo thermal techniques, Solution growth techniques, Thermal evaporation/PLD/CVD, Sol-gel processing, Electrodeposition, Phase identification through X-ray diffraction (XRD), Study of microstructure-electron microscopy: Scanning electron microscopy (SEM), Transmission electron microscopy (TEM). Introduction to Scanning Probe Microscopy (SPM): Atomic Force Microscopy (AFM) and Scanning Tunnelling Microscopy (STM). Characterization of defects by Positron annihilation lifetime spectroscopy.

Module 3: Electrons in Nanostructures (*15 Hours*)

Variation in electronic properties of materials, Quantum effect, Fermi liquids and free electron model, Electrons in crystalline solids (2D and 3D), Fermi surface and Brillouin zones, Electron passing through tiny structures: Landauer resistance. Single-Electron Devices: electron transport in nanoscilicon, Coulomb blocked and resonant tunneling effect, Electron localization and system size.

Application: Resonant Tunneling Transistor, Single-Electron Transistors, Nano-robotics and Nano-manipulation, Molecular Nano-devices, Nano-computers, Theoretical Models, Optical Fibers for Nano-devices; GaN, based Nano devices. ZnO Nano-structure and its application in photonics, DNA-Based Nano devices; Carbon Nano tubes and Nano tube based devices.

Module 4: Molecular-Electronics (*10 Hours)*

Introduction to molecular electronics, Lewis structures as a simple guide to chemical bonding, variational approach to calculate molecular orbital, Hybridization of atomic orbital’s, Molecular levels in organic compounds. Delocalization energy: Quantifying donor and acceptor properties with electrochemistry. Electron transfer between molecules; Marcus Theory, Charge transport between weakly interacting molecule solids: hopping conductance. Dimensionality: 1D conductor and conducting polymers, single molecule electronics, the transition from tunneling to hopping conductance in single molecule.

Module 5: Electronic and Photonic Materials (*5 Hours)*

Over view of Quantum well lasers, Quantum cascade lasers, Quantum dot lasers, Quantum wire lasers. White LEDs, LEDs based on nano-wires, LEDs based on nano-tubes, LEDs based on nanorods, Quantum well infrared photo detectors.

Reference Books:

1. Nanochemistry: A chemical approach to nanomaterials by G. A. Ozin, A. C. Aresnault, L. Cadematriri, RSCPublishing
2. Chemistry of nanomaterials: Synthesis, properties and applications by CNR Rao et.al.
3. Nanoparticles: From theory to applications; G. Schmidt, Wiley Weinheim 2004.
4. Fabrication of fine pitch gratings by holography, electron beam lithography and nano-imprint lithography (Proceedings Paper) Author(s): Darren Goodchild; Alexei Bogdanov; Simon Wingar; Bill Benyon; Nak Kim; Frank Shepherd
5. A Three Beam Approach to TEM Preparation Using In-situ Low Voltage Argon Ion Final Milling in a FIBSEM
6. Nanochemistry: A Chemical Approach to Nanomaterials; Royal Society of Chemistry, Cambridge UK 2005.
7. Nanocomposite science and technology; P.M. Ajayan, L.S. Schadler, P.V. Braun, Wiley, New York.

Paper Name: ***Particle Physics***
Paper Code: **PHY514**
Credit: **4**
LTP: **4-0-0**

Course Objectives:
By the end of the course, students will be able to:

1. **Introduce** the fundamental constituents of matter and their interactions, including particle classification, internal quantum numbers, conservation laws, and discrete symmetries.

2. **Develop** a working knowledge of group theory and Lie groups, and to **apply** representation theory to the study of internal symmetries in particle physics.

3. **Formulate** globally and locally invariant Lagrangians using the gauge principle and to **construct** Abelian and non-Abelian gauge theories relevant to particle interactions.

4. **Explain** the mechanism of spontaneous symmetry breaking and the Higgs mechanism as the origin of mass generation in gauge theories.

5. **Provide** a coherent understanding of the electroweak theory and the structure of the Standard Model, including fermion representations and mixing phenomena.

Course Description:
This postgraduate course provides a systematic introduction to modern particle physics, combining phenomenology with theoretical foundations. It begins with the classification of elementary particles, their quantum numbers, conservation laws, and fundamental interactions. The course then develops the mathematical framework of group theory and Lie groups and applies it to internal symmetries and particle multiplets. Building on symmetry principles, students construct globally and locally invariant Lagrangians and formulate Abelian and non-Abelian gauge theories, including QED and QCD. The course further explores spontaneous symmetry breaking and the Higgs mechanism as the origin of mass generation. It culminates in the electroweak theory and an overview of the structure of the Standard Model, preparing students for advanced study in high energy and theoretical physics.

Course Outcomes:

CO1: Demonstrate a comprehensive understanding of symmetry principles, conservation laws, and quantum numbers in describing fundamental particles and their interactions.

CO2: Apply mathematical structures such as group theory, Lie algebras, and representation theory to **analyse** symmetry properties in particle physics.

CO3: Construct and **interpret** invariant Lagrangians based on symmetry principles and gauge invariance, and **explain** their physical implications for particle interactions.

CO4: Analyse mechanisms that determine interaction structure and particle masses, including gauge symmetry and symmetry breaking phenomena.

CO5: Critically **examine** the theoretical framework of modern particle physics and **synthesize** its mathematical and physical principles to describe the structure of the Standard Model.

Course Content

Module 1: Foundations of Elementary Particle Physics (15 Hours)

Particle classification, fermions and bosons, quarks and leptons, generations of fermions, gauge bosons and mediators of interactions, hadrons (mesons and baryons), resonance particles, fundamental interactions (strong, electromagnetic, weak, gravitational – qualitative), Feynman diagrams (tree-level processes), internal quantum numbers (electric charge, baryon number, lepton number, isospin, strangeness, charm, bottomness, topness), Gell-Mann–Nishijima formula, conservation laws and selection rules, Eightfold Way (conceptual), quark model of hadrons, discrete symmetries (C, P, T), CPT theorem, CP violation in weak interactions (qualitative), properties of neutrinos, quark–lepton symmetry.

Module 2: Group Theory and Lie Groups in Particle Physics (10 Hours)

Basic group theory (definitions, representations, homomorphisms), continuous groups and Lie groups, Lie algebras, generators and structure constants, representations of Lie groups and Lie algebras, Casimir operators, SU(2), SU(3) and U(1) groups, representation theory of SU(2) (spin and angular momentum), SU(3) flavour symmetry and multiplet classification, fundamental and adjoint representations, tensor product decompositions, applications to internal symmetries in particle physics.

Module 3: Gauge Theories and Invariant Lagrangians (15 Hours)

Global internal symmetries and invariant Lagrangians, local gauge invariance and gauge principle, covariant derivative, gauge field strength tensor, Abelian gauge theory, invariant Lagrangian of Quantum Electrodynamics (QED), conserved currents in QED, scalar Quantum Electrodynamics (scalar QED) and minimal coupling, non-Abelian gauge transformations, Yang–Mills theory, construction of Quantum Chromodynamics (QCD) Lagrangian, SU(3) colour symmetry, self-interaction of non-Abelian gauge fields, qualitative discussion of confinement.

Module 4: Spontaneous Symmetry Breaking and the Standard Model (15 Hours)

Spontaneous symmetry breaking (global symmetries), Goldstone theorem, linear sigma model, Higgs mechanism, Abelian Higgs model, mass generation for gauge bosons, $SU(2)_L \times U(1)_Y$ electroweak gauge symmetry, electroweak Lagrangian, spontaneous symmetry breaking in electroweak theory, Weinberg angle, masses of W and Z bosons, fermion mass generation, structure of the Standard Model, fermion representations under gauge groups, gauge interactions of quarks and leptons, CKM matrix (qualitative discussion), overview of the complete Standard Model Lagrangian.

References:

1. I. J. R. Aitchison and A. J. G. Hey, *Gauge Theories in Particle Physics: A Practical Introduction*, CRC Press, 4th Edition, 2012.
2. Palash B. Pal, *An Introductory Course of Particle Physics*, CRC Press, 1st Edition, 2014.
3. Giovanni Costa and Gianluigi Fogli, *Symmetries and Group Theory in Particle Physics: An Introduction to Space-Time and Internal Symmetries*, Springer, 1st Edition, 2012.
4. Howard Georgi, *Lie Algebras in Particle Physics: From Isospin to Unified Theories*, Westview Press, 2nd Edition, 1999.
5. F. Scheck, *Electroweak and Strong Interactions: An Introduction to Theoretical Particle Physics*, Springer, 1st Edition, 2012.
6. David J. Griffiths, *Introduction to Elementary Particles*, Wiley-VCH, 2nd Edition, 2008.
7. Frank Close, *An Introduction to Quarks and Partons*, Academic Press, 1st Edition, 1979.

Paper Name: ***Collective Phenomena in Solids***

Paper Code: **PHY515**

Credit: **4**

LTP: **4-0-0**

Course Objectives:

By the end of the course, students will be able to:

1. Understand the fundamental dielectric, optical, transport, magnetic, and superconducting properties of condensed matter systems, and how they arise from underlying microscopic phenomena.
2. Analyze the interaction of electromagnetic radiation with materials, including reflection, absorption, and optical transitions, and interpret their signatures in experimental spectra.
3. Apply classical and quantum models such as the Drude model, Boltzmann transport theory, and BCS theory to describe electronic, thermal, and superconducting behaviors.
4. Evaluate experimental techniques like dielectric spectroscopy, four-point probe, SQUID magnetometry, and STM in the characterization of material properties.
5. Discuss the application of advanced material properties in modern technologies including optoelectronics, thermoelectrics, spintronics, and quantum devices.

Course Description:

This course provides an in-depth understanding of advanced physical phenomena in condensed matter systems, focusing on the interplay between microscopic interactions and macroscopic material properties. The course covers dielectric and optical responses, including polarization mechanisms, dielectric losses, and light–matter interactions. It introduces classical and semi-classical transport theories to describe electrical and thermal conduction in metals, semiconductors, and low-dimensional systems, alongside thermoelectric effects.

Magnetic properties are studied from both localized and itinerant perspectives, covering magnetic ordering, spin-wave excitations, and exchange mechanisms. The course also introduces superconductivity, emphasizing the BCS theory, Cooper pairing, energy gap formation, and quantum tunneling effects like the Josephson effect. Practical insights are provided through discussions of state-of-the-art experimental techniques such as dielectric spectroscopy, magnetometry, and STM, along with emerging applications in optoelectronics, quantum computing, and spintronics. This course is ideal for students aiming for careers or research in experimental and theoretical condensed matter physics, materials science, and advanced device technologies.

Course Outcomes:

CO1: Explain dielectric polarization mechanisms, optical constants, and energy loss phenomena in dielectric and photonic materials.

CO2: Apply the use of transport models to describe electrical and thermal conduction in metals and semiconductors, and assess thermoelectric and Hall effects.

CO3: Analyze various types of magnetic ordering and spin-wave phenomena using quantum models such as the Heisenberg and Ising models.

CO4: Illustrate the key concepts of superconductivity including Cooper pairing, energy gap estimation, and Josephson junctions, and explain their real-world applications.

CO5: Evaluate and select suitable experimental tools (e.g., dielectric spectroscopy, SQUID, STM, ellipsometry) for characterizing the electrical, optical, and magnetic properties of advanced materials.

Course Content:

Module 1: Dielectric and Optical Properties of Materials (*14 Hours*)

Fundamentals of Dielectric Response (Dielectric function and complex dielectric constant, Electronic, ionic, and orientation polarizabilities, Harmonic oscillator model of dielectric function, Dielectric loss, dielectric strength, relaxation time, Longitudinal vs transverse polarization), Dispersion Relations and Loss Mechanisms (Kramer–Kronig relations and causality, Lyddane–Sachs–Teller relation, Dielectric energy loss and loss tangent, Absorption of EM radiation in optically thick/thin media), Interaction of EM Waves with Materials (Reflection, refraction, and absorption, Optical constants: Refractive index, extinction coefficient, Interband and intraband transition, Electronic band structure and optical transitions), Vibrational and Collective Excitations (Polaron, polariton, and plasmon basics, Plasma oscillations and Wood-Zener effect, IR-active and inactive modes in ferroelectrics), Ferroelectric phase transitions: First and second order, Dielectric spectroscopy and impedance analysis, Ellipsometry, Photoluminescence and Raman spectroscopy basics, Introduction to nonlinear optical materials, Photonic crystals and metamaterials, Applications: LEDs, solar cells, and lasers.

Module 2: Transport Phenomena in Condensed Matter (*14 Hours*)

Drude Model: Classical electron transport, conductivity, and relaxation time; Boltzmann Transport Equation (BTE): Basic form, assumptions, and solutions under relaxation time approximation; Electrical Conductivity and Resistivity: Temperature and impurity dependence; Scattering Mechanisms: Impurities, phonons, and grain boundaries; Thermoelectric Effects and Phonon Transport (Seebeck, Peltier, and Thomson Effects); Thermal conductivity in crystals; Electron-Phonon Interaction: Role in transport and superconductivity (qualitative); Experimental Techniques in Transport Studies: Electrical transport measurement (four-point probe), Thermal transport (Laser flash analysis), magneto-transport measurements (Hall effect, magnetoresistance); 2D Electron gas and its Density of States; Landau band formation and Quantum Hall effect, Spin Hall Effect (Qualitative discussions only); Discussion only: Topological phases of Matter, TI and Dirac semimetals, Winding number and Zak phase.

Module 3: Advance Concepts in Magnetism (*14 Hours*)

Introduction, Bohr–van Leeuwen theorem (classical failure of magnetism), Magnetic dipole-dipole interactions, Magnetic moments of free atoms and ions, Magnetism in crystals (Crystal field effects on magnetic ions, transition metal ions & orbital quenching, Jahn–Teller effect in magnetic systems), Exchange Interactions (Origin, Types: Direct, Indirect (RKKY), Super exchange, Itinerant exchange), Mean Field Theory & Magnetic Ordering (Mean field theory for magnetic insulators, Weiss molecular field, Curie–Weiss law, Concept of spontaneous magnetization, Ferri- and antiferromagnetism), Concept of spin waves in ferromagnets, Heisenberg ferromagnet, Thermodynamics of magnons, Holstein–Primakoff transformation, Heisenberg antiferromagnet, Spin-waves in lattices with a basis, Magnetic ordering in metals

Stoner criterion for ferromagnetism, The Ising model, Brief intro to t–J model and Nagaoka ferromagnetism, Experimental Techniques: SQUID, VSM, Neutron and X-ray scattering in magnetic systems, Magnetic Force Microscopy (MFM)

Module 4: Superconductivity (*14 Hours*)

Fundamental physics of superconductivity, Phenomenon of zero resistance and the Meissner effect, London equations and Type I and Type II superconductors, Cooper pairing, Qualitative understanding of the BCS Hamiltonian: ground state wavefunction, and the estimation of energy gap and its temperature dependence, Bogoliubov transformation and the diagonalization of the BCS Hamiltonian, offering physical insights into quasiparticles, The Josephson effect and Josephson junctions are discussed with applications to SQUIDs, Basic introduction to Andreev reflection and its relevance in hybrid superconducting systems. Experimental techniques: SQUID, STM, Applications in superconducting magnets (e.g., MRI), Superconducting electronics: Quantum computing and microwave devices, Future directions: Room-temperature superconductors and superconducting spintronics.

References:

1. Optical Properties of Solids: Mark Fox, Oxford Master series
1. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiments
2. Solid State Physics: Essential Concepts, avid W. Snoke.
3. J.M. Ziman: Principles of the Theory of Solids
4. Electronic Transport in Mesoscopic systems: Supriyo Datta, Cambridge Universuty Press
5. Quantum Transport: Atom to Transistor, Supriyo Datta, Cambridge Universuty Press
6. Lessons from Nanoelectronics: Supriyo Datta
7. Introduction to Solid State Physics" by Charles Kittel
8. "Principles of Condensed Matter Physics" by P. M. Chaikin and T. C. Lubensky
9. "Magnetism in Condensed Matter" by Stephen Blundell
10. "Superconductivity: A Very Short Introduction" by Stephen Blundell

Paper Name: ***Imaging and Spectroscopy in Medical Diagnostics***
Paper Code: **PHY516**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

By the end of the course, students will be able to:

1. Explain the fundamental physical principles governing various medical imaging modalities (X-ray, CT, Ultrasound, MRI, Nuclear Medicine, Optical Imaging).
2. Describe the basic instrumentation, components, and operational mechanisms of each imaging system.
3. Analyze the advantages, limitations, safety considerations, and diverse clinical applications of different imaging techniques.
4. Apply essential image processing algorithms using MATLAB for medical image enhancement, segmentation, feature extraction, and quantitative analysis.
5. Understand the principles, instrumentation, and diagnostic applications of key spectroscopic techniques (IR, Raman, NMR, UV-Vis, Fluorescence) in medicine.
6. Critically evaluate and interpret medical imaging and spectroscopic data for diagnostic and research purposes.

Course Description:

This course offers a comprehensive exploration of the fundamental principles, instrumentation, and clinical applications of major medical imaging modalities and cutting-edge spectroscopic techniques vital for modern medical diagnostics. Students will delve into the underlying physics of image formation, master essential image processing techniques using MATLAB for quantitative analysis, and gain an understanding of how spectroscopic methods contribute to disease detection and monitoring. The curriculum emphasizes a blend of theoretical knowledge with practical skills essential for researchers and professionals in biomedical engineering and related fields.

Course Outcomes:

CO1: Recall the principles and techniques of various medical imaging modalities such as X-ray, CT, MRI, PET, and SPECT.

CO2: Explain the fundamentals of image perception, image sampling, quantization, and transforms like 2D-DFT in the context of medical imaging.

CO3: Apply image processing and classification techniques, including enhancement, restoration, and segmentation, to analyze and interpret medical images.

CO4: Analyze reconstruction techniques for CT and MRI images, including radon transforms, filter back projection, and Fourier methods.

CO5: Evaluate the efficiency and accuracy of medical image transmission systems using techniques like transform, pixel, and predictive coding.

CO6: Design spectroscopic techniques for biomolecular analysis and diagnostics, such as blood oxygen measurement, glucose monitoring, and cancer diagnosis, leveraging principles of UV-Vis, IR, FTIR, and NMR spectroscopy.

Course Content

Module 1: Medical Imaging Modalities *(15 hours)*

Generation and detection of X-rays (radiography techniques). Principle and Theory of computer tomography (CT) scanning, spiral CT scanning and (positron emission tomography) PET scan. Physics of MRI imaging and its application in the field of diagnostics. Reconstruction of CT and MRI Images. Advantage and disadvantage of the NMR imaging as against other medical imaging methods. Gamma camera, single photon emission computer tomography (SPECT) and other latest medical imaging systems. Image quality description and patient risk, Safety protocols and regulatory frameworks. Theory and applications of optical, thermography imaging.

Module 2: Image Fundamentals *(8 hours)*

Image Perception, MTF of the visual system, image fidelity criteria, image model, image sampling and quantization – 2 dimensional sampling theory, image quantization, optimum mean square quantizer, image transforms- 2 D – DFT and other transforms.

Module 3: Image processing, analysis and classification *(12 hours)*

Image enhancement –point operation, histogram modelling, spatial operation, transforms operations. Image restoration- image degradation model, inverse and wiener filtering. Image analysis- spatial feature extraction, edge detection, image segmentation classification technique-statistical methods, neural network approaches. AI based approaches.

Module 4: Transmission of Medical Images *(10 hours)*

Transmission of Medical Images: Medical Image, Data compression and transmission, Transform coding, pixel coding, predictive coding, interframe coding.

Module 5: Spectroscopic Techniques *(15 hours)*

Optical characteristics of biomolecules from the point of spectroscopy – principles of UV – Visible absorption – IR and FTIR absorption – Raman and Fluorescence spectroscopy – application with regard to characterization of biomolecules – blood oxygen, glucose measurements, monitoring drug concentration, cancer diagnosis. Nuclear spin and nuclear magnetic moment. The hyperfine structure of the spectra. SternGerlach method and NMR methods (Rabi, Bloch and Purcell) to measure the nuclear magnetic moments. NMR spectroscopy. Biological tissues magnetization.

References:

1. Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2012). *The Essential Physics of Medical Imaging*. Lippincott Williams & Wilkins.
2. Prince, J. L., & Links, J. M. (2014). *Medical Imaging Signals and Systems*. Pearson Prentice Hall.
3. Zeng, G. L. (2010). *Medical Imaging: Principles and Practices*. CRC Press.
4. Gonzalez, R. C., & Woods, R. E. (2018). *Digital Image Processing*. Pearson.
5. Webb, S. (Ed.). (2003). *The Physics of Medical Imaging*. CRC Press.
6. Chopra, S. C., & Sahu, A. (2020). *Medical Physics*. Springer.
7. Skoog, D. A., Holler, F. J., & Crouch, S. R. (2017). *Principles of Instrumental Analysis*. Cengage Learning.
8. Relevant research papers and review articles from prominent journals

Paper Name: ***Astrophysics and Cosmology II***
Paper Code: **PHY517**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

The objectives of this course are to:

1. Provide a deep understanding of the physics of compact stars, galaxies, and large-scale structures of the Universe.
2. Introduce students to the processes that govern the thermal and dynamical evolution of the Universe.
3. Develop the ability to analyse observational data and theoretical models in modern cosmology and astrophysics.
4. Familiarize students with the generation, detection, and astrophysical relevance of gravitational radiation.
5. Prepare students for advanced research in astrophysics, cosmology, and gravitational wave astronomy.

Course Description:

This course builds upon *Astrophysics & Cosmology I* and introduces students to advanced topics in astrophysics and cosmology. It covers the physics of compact stars, galactic structure and dynamics, and the formation of large-scale cosmic structures. The thermal history of the Universe and the observational implications of the Cosmic Microwave Background are explored in depth. The course also addresses the role of dark matter and dark energy in cosmic evolution, the growth of density perturbations, and the emergence of large-scale structure. Finally, the course introduces the fundamentals of gravitational radiation and its applications in modern astrophysics and cosmology. The material is designed to prepare students for further study and research in the field.

Course Outcomes:

CO1: **Analyze** the structure and stability of compact objects using relativistic equations of state, TOV formalism, and solutions such as Schwarzschild and Kerr geometries.

CO2: **Apply** radiation theory and energy transport mechanisms to interpret astrophysical processes in stellar and high-energy environments.

CO3: **Evaluate** galactic structure and dynamics, including rotation curves, dark matter evidence, gravitational lensing, and the role of supermassive black holes.

CO4: Interpret the thermal history of the Universe, including inflation, Big Bang nucleosynthesis, recombination, baryogenesis, and constraints from the cosmic microwave background.

CO5: **Explain** the theoretical foundations and astrophysical sources of gravitational waves, and assess detection principles in experiments such as LIGO, Virgo, KAGRA, and LISA.

Course Content

Module 1: Physics of Compact objects *(14 Hours)*

White dwarfs: equation of state, mass-radius relation, Chandrasekhar limit,

Neutron stars: Structure and mass-radius relation, Application of the TOV equation

Black holes: Schwarzschild solution, Reissner-Nordstrom solution and Kerr solution (qualitative), Concept of event horizon, astrophysical evidence.

Module 2: Radiative Process *(5 Hours)*

Radiation theory and Larmor formula, Different radiative processes with special emphasis on radiative and convection transport of energy.

Module 3: Galactic Astrophysics *(12 Hours)*

Structure of the Milky Way, Galaxy classification and morphological properties, Galaxy rotation curves and evidence for dark matter, Galaxy formation and evolution, Interactions and mergers, Galaxy clusters, Properties and observational signatures, gravitational lensing, X-ray emission, Supermassive black holes

Module 4: Thermal History of the Universe *(12 Hours)*

Cosmic Inflation: motivation, basic models, primordial perturbations.

Reheating: Big Bang nucleosynthesis (BBN), Processes and element abundance predictions, Observational constraints, Recombination and photon decoupling, Baryon asymmetry.

Cosmic Microwave Background (CMB): primary and secondary anisotropies, Reionization epoch, Constraints on cosmology from CMB observations.

Module 5: Basic Ideas of Gravitational Radiation *(8 Hours)*

Theory of Gravitational Wave: Linearized Einstein equations and wave equation, Gravitational wave polarizations, Transverse-Traceless gauge.

Sources: Binary inspirals, Black hole mergers, Primordial background.

Detectors: LIGO, Virgo, KAGRA, LISA (qualitative).

References:

1. M. L Kutner, *Astronomy: A Physical Perspective*, Cambridge University Press, 2003.
2. B. W. Carrol and D. A. Ostlie, *An Introduction to Modern Astrophysics*, Pearson, 2006.
3. T. Padmanabhan, *Theoretical Astrophysics: Galaxies and Cosmology (Volume III)*, Cambridge University Press, 2010.
4. Arnab Rai Choudhuri, *Astrophysics for Physicists*, Cambridge University Press, 2010.
5. N. Straumann, General Relativity with Applications to Astrophysics, Springer, 2010.
6. G. B. Rybicki and A. P. Lightman, *Radiative Processes in Astrophysics*, Wiley, 1979.
7. S. L. Shapiro and S. A. Teukolsky, *Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects*, Wiley-VCH, 1983.
8. T. Padmanabhan, *Structure Formation in the Universe*, Cambridge University Press, 1993.
9. M. Longair, *Galaxy Formation*, Springer, 2013.
10. J. Binney and M. Merrifield, *Galactic Astronomy*, Princeton University Press, 1999.
11. S. Weinberg, *Cosmology*, Oxford University Press, 2019.
12. Scott Dodelson, *Modern Cosmology*, Academic Press Inc, 2nd edition, 2020.
13. T. Padmanabhan, *Cosmology and Astrophysics Through Problems*, Cambridge University Press, 1996.
14. Barbara Ryden, *Introduction to Cosmology*, Cambridge University Press, 2nd edition, 2016.

Paper Name: ***Optoelectronic Devices***
Paper Code: **PHY518**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. I**ntroduce** the fundamental concepts of laser physics, including population inversion, laser oscillation, and optical amplification mechanisms.

2. **Familiarize** students with different types of lasers and their structural, operational, and functional characteristics.

3. **Provide** a comprehensive understanding of photodetectors and optoelectronic modulators, including their working principles and performance parameters.

4.D**evelop** knowledge of integrated optics, fiber-optic components, and their applications in modern optoelectronic systems.

5. **Expose** students to advanced applications of optoelectronic devices in fields such as LIDAR, remote sensing, material processing, navigation, and spacecraft instrumentation.

Course Description:

This course provides an in-depth study of optoelectronic devices and systems, focusing on their physical principles, design, and applications. Topics include the fundamentals of laser operation, optical amplification, resonator configurations, and various types of lasers such as gas, solid-state, semiconductor, and dye lasers. The course covers key optoelectronic components such as photodetectors, modulators, fiber-optic systems, and integrated optics. Emphasis is placed on real-world applications, including material processing, LIDAR, metrology, remote sensing, and spacecraft optical systems. Through this course, students will gain the knowledge necessary to analyze, design, and evaluate modern optoelectronic devices used in scientific, industrial, and space-based applications.

Course Outcomes:

CO1. Explain the fundamental principles of laser operation, optical amplification, and resonator configurations.

CO2. Compare and categorize various types of lasers and their working mechanisms, including gas, solid-state, semiconductor, and free-electron lasers.

CO3. Evaluate the performance and application of photodetectors and optoelectronic modulators in optical communication and sensing systems.

CO4. Design basic integrated optical systems, including fiber-optic components and optical amplification setups for practical applications.

CO5. Assess the use of optoelectronic devices in advanced applications such as LIDAR, remote sensing, spacecraft navigation, and material processing.

Course Content

Module I: Fundamentals of Lasers and Optical Amplifiers (14 Lecture Hours)

Unit 1: Laser Principles and Oscillation (4 hours)

Laser oscillation above threshold, gain and feedback, Population inversion and conditions for lasing, Rate equations for three-level and four-level systems,Laser pumping mechanisms, Laser amplifier basics

Unit 2: Laser Cavities and Resonators (4 hours)

Laser cavity modes, stable resonators, Gaussian beam optics, Q-switching, Mode locking, Pulse generation and compression techniques

Unit 3: Optical Amplifiers and Coupled Mode Theory (6 hours)

Optical amplification principles, Erbium-doped fiber amplifiers (EDFA), Raman amplifiers, Wide-band fiber amplifiers, Coupled-mode theory: degenerate and non-degenerate coupling, Applications: waveguide coupling, fiber splicing and connectors

Module II: Types of Lasers and Their Applications (15 Lecture Hours)

Unit 4: Types of Lasers (10 hours)

Gas lasers: He-Ne, Argon Ion, He-Cd, Molecular lasers: CO_2, Excimer, Nitrogen, X-ray plasma lasers, free-electron lasers, Dye lasers, solid-state lasers: Ruby, Nd:YAG, Alexandrite, Ti:Sapphire, Semiconductor lasers: LED, edge-emitting, VCSEL, DFB, DBR, quantum well lasers

Unit 5: Laser Applications (5 hours)

LIDAR and its types: Doppler wind LIDAR, DIAL, Material processing: CO_2, YAG, Excimer lasers in cutting, welding, drilling, Metrology and holography applications, Laser-based navigation and free-space communication

Module III: Photodetectors and Modulation Techniques (12 Lecture Hours)

Unit 6: Optical Radiation Detection (6 hours)

Principles of detection: photon vs thermal detectors, Photomultipliers, photodiodes, avalanche photodiodes, CCDs, Image Intensifiers, CID, FLIR, Noise sources and performance metrics, Solar cells and optical arrays

Unit 7: Optoelectronic Modulators (6 hours)

Principles of modulation and birefringence, Electro-optic (EO), acousto-optic (AO), and magneto-optic (MO) effects, Common modulators and performance characteristics

Module IV: Integrated Optics, Sensors, and Space Applications (19 Lecture Hours)

Unit 8: Integrated and Fiber Optic Devices (4 hours)

Optical integrated circuits, Fiber-optic components: splicing, connectors, joints, Applications of integrated optics in miniaturized systems

Unit 9: Sensors and Instrumentation (6 hours)

Photometry and Radiometry, Radiation sources and detector classification, Sensor optics and instrumentation, Signal conditioning and processing

Unit 10: Space Optoelectronics (9 hours)

Spacecraft optical sensors: Fiber optic and ring laser gyros, star trackers; Remote sensing: IR sensors, hyperspectral imagers; Space metrology and pointing/navigation systems; Design, calibration, and performance evaluation of space sensors

Reference Books:

1. Laser Fundamentals – W.T. Silfvast, Second Edition, Cambridge University Press, 2004

2. Principles of Lasers – O. Svelto, Fourth edition, Springer, 1998
3. Photonics: Optical Electronics in Modern Communications – A. Yariv and P. Yeh, Sixth Edition, Oxford University Press, 2007
4. Semiconductor Optoelectronic devices – Pallab Bhattacharya, Prentice Hall of India, 1995
5. Semiconductor Optoelectronics – Jasprit Singh, Tata Mc Graw Hill, 1995
6. Optoelectronics - an Introduction – Wilson and Hawkes, Prentice Hall, 1998
7. Infrared Photon detectors-Antoni Rogalski [Ed]-SPIE Optical Engineering Press-1995
8. CCD arrays, Cameras and Displays-Gerald C Hoist 1998 [2nd Ed], JCD Publishing-SPIE Optical Engg.Press
9. Introduction to Fiber Optics, Ghatak and Thyagarajan, Cambridge University Press (2009)
10. Foundations for Guided wave Optics, Chin-Lin Chen, John Wiley and Sons (2007)
11. Optical Fiber Communications, Gerd Keiser, Fourth Edition, Tata McGraw Hill (2008)
12. Optical Fiber communications, J M Senior, Prentice Hall of India (1994)
13. Fundamentals of Optoelectronics, C R Pollock, Irwin Inc., (1995)
14. Essential Macloed Software, By Angus Macleod Fundamentals of Space Systems by Vincent L. Pisacane, Oxford University Press, 2005
15. Spacecraft dynamics and Control: A practical Engineering approach- Marcel J.Sidi, Contributor Michael J.Rycroft, Wei Shyy, Cambridge University Press, 2000,
16. Spacecraft Attitude determination and Control by Computer Sciences, Corporation Attitude Systems operation, James Richrad Wertz, Springer, 1978,
17. Scientific Charge Coupled devices, James R.Janesick, SPIE Press

Paper Name: ***Nanoelectronics and Nanophotonics***

Paper Code: **PHY519**

Credit: **4**

LTP: **4-0-0**

Course Objectives:

By the end of the course, students will be able to:

1. Enable students to grasp advanced concepts in free electron theory, quantum conductance, and electron transport in nano-materials.
2. Guide students in applying theoretical knowledge to analyze and solve complex problems in nano-electronics and related fields.
3. Foster critical evaluation of methodologies and practices in experimental and computational physics, particularly in nano-scale systems.
4. Support students in developing robust experimental designs and data analysis techniques relevant to modern physics research.

Course Description:

This course introduces the fundamental principles of electron transport in materials, spanning classical models (Drude, Sommerfeld) to quantum phenomena such as quantized conductance and Coulomb blockade. It covers the behavior of electrons in low-dimensional systems—quantum wells, wires, and dots—and explores key materials for nanoelectronics, including semiconductors, nanowires, organic semiconductors, and carbon nanomaterials. Topics include electron and phonon transport, thermoelectric effects, Hall effect, spin transport, and interface resistance. Device applications such as p-n junctions, resonant-tunneling diodes, FETs, single-electron transistors, and quantum-dot cellular automata are discussed. The course bridges theory and application, equipping students to understand and work with modern nanoscale electronic devices.

Course Outcomes:

CO1: Recall fundamental principles of free electron theory, quantum conductance, and materials used in nanoelectronics.
CO2: Explain the principles of ballistic and diffusive transport, electron transport in semiconductors, and the role of phonon transport in thermal conductivity.
CO3: Apply theoretical models to analyze electron transport in low-dimensional structures such as quantum wells, wires, and dots, and interpret their behavior numerically.
CO4: Analyze thermoelectric effects, Hall Effect, and the behavior of smart contacts in nanostructured devices.
CO5: Evaluate the performance of nanostructure devices such as spin valves, resonant-tunneling diodes, and quantum-dot cellular automata, considering their design constraints and functionalities.

Course Content

Module 1: Free Electron Theory and quantum of conductance (*10 Hours*)
Why Electrons flow, Classical free electron theory, Sommerfeld's theory, the quantum of conductance, Coulomb blockade, Towards Ohm's law. The Elastic Resistor: Conductance of an Elastic Resistor, Elastic Resistor- Heat dissipation.
Materials for nano electronics: Semiconductors, Crystal lattices: bonding in crystals, Electron energy bands, Semiconductor heterostructures, Lattice-matched and pseudo morphic hetero-structures, Inorganic nanowires, Organic semiconductors, Carbon nanomaterials: nanotubes and fullerenes

Module 2: Ballistic and Diffusive Transport (*10 Hours*)
Ballistic and Diffusive Transfer Times, Channels for Conduction Conductivity, Conductivity: E(p) or E(k) Relations, Counting States, Drude Formula, Quantized Conductance, Electron Density -Conductivity

Module 3: Electron transport in semiconductors and nanostructures (*8 Hours*)
Time and length scales of the electrons in solids, Statistics of the electrons in solids and nanostructures, Fermi statistics for electrons, the density of states of electrons in nanostructures, Electron transport in nanostructures.

Module 4: Electrons in traditional low-dimensional structures (*8 Hours*)
Electrons in quantum wells: Single modulation-doped heterojunctions, Numerical analysis of a single heterojunction, Control of charge transfer, Electrons in quantum wires, Electron transport in quantum wires, Electrons in quantum dots.

Module 5: Smart Contacts and Phonon Transport (*8 Hours*)
Why p-n Junctions are different, Current-Voltage Characteristics, Contacts are fundamentals. *Thermoelectricity***:** Seebeck Coefficient, Thermoelectric Figures of Merit, Heat Current. *Phonon Transport***:** Phonon Heat Current, Ballistic phonon transport, Thermal Conductivity. *Hall Effect***:** N- and P- Conductors, Spatial profile of Electrochemical potential, Measuring the Potential, Non –Reciprocal Circuits.

Module 6: Spin Valves and Nanostructure devices (*10 Hours*)
Mode Mismatch and Interface Resistance, Spin Potentials, Spin-Torque, Polarizers and Analyzers, Kubo formula for an elastic resistor: One level resistor, Elastic resistor, Onsager relations. Resonant-tunneling diodes, Field-effect transistors Single-electron-transfer devices, Potential-effect transistors, Light-emitting diodes and lasers, Quantum-dot cellular automata.

Reference Book:

1. Supriyo Dutta; Lessons from Nanoscience: A Lecture Note Series, World Scientific (2012).
2. Supriyo Dutta; Quantum Transport- Atom to Transistor, Cambridge University Press (2005).

3. V. Mitin, V. Kochelap, M. Stroscio, Introduction to Nanoelectronics, Cambridge University Press (2008).
4. Rainer Waser, Nanoelectronics and Information Technology: Advanced Electronic Materials and Novel Device, Wiley-VCH (2003).
5. Karl Goser, Peter Glosekotter, Jan Dienstuhl, Nano-electronics and Nanosystems, Springer (2004).
6. Introduction to Nano-electronics : Science, Nanotechnology, Engineering and Applications by Vladimir.V.Mitin.

Paper Name: *High Energy Physics Lab*
Paper Code: PHY520
LTP: 0-0-2

Course Objectives:

1. To develop practical skills in radiation and cosmic ray detection techniques using modern instruments.
2. To understand and quantify statistical fluctuations and uncertainties in nuclear measurements.
3. To analyze spectral and angular data related to radiation interactions and cosmic ray flux.
4. To apply numerical and statistical tools including curve fitting and Monte Carlo simulations.
5. To introduce ROOT software for high energy physics data analysis and visualization.

Course Description:

This laboratory course provides practical exposure to key experimental techniques in high energy and nuclear physics. Students will perform experiments related to cosmic ray detection, radiation interaction with matter, and nuclear spectroscopy using modern detection systems such as scintillators, Geiger-Müller tubes, and gamma ray spectrometers. The course also introduces data analysis techniques, uncertainty quantification, and the use of advanced tools such as ROOT for scientific computing and Monte Carlo simulations in particle physics research.

Course Outcomes:

CO1: Recall principles of radiation detection, cosmic ray interactions, and fundamental statistical concepts relevant to nuclear measurements.

CO2: Explain the operational features of detectors and the significance of experimental parameters and data acquisition techniques.

CO3: Conduct high energy physics experiments and apply basic statistical and computational techniques for data recording and interpretation.

CO4: Analyze experimental data using error analysis, curve fitting, and interpret results using Monte Carlo

CO5: Design and implement data processing workflows using ROOT or Python to visualize and evaluate experimental outcomes in particle physics.

Course Content

List of Experiments

Part A: Experimental Investigations in High Energy Physics

1. Detection of Cosmic Rays using a System of Three Plastic Scintillating Tiles and Measurement of Zenith Dependence of Cosmic Ray Flux as a Function of Altitude
2. To study characteristics of G.M. Tube: operating voltage, slope, efficiency and resolving time of G.M. tube
3. To study the statistics of radioisotope measurements and observe the effects of backgrounds on the counting statistics
4. Determination of energy spectrum of the give radionuclide using Gamma Ray Spectrometer and Identification of unknown radionuclide through Gamma Ray Spectrometer
5. Demonstration of Inverse Square Law for Gamma Rays
6. Determination of Beta Particle Range and Maximum Energy (Half-Thickness Method)
7. Study of Backscattering of Beta Particles

Part B: Statistical and Computational Data Analysis

- Classification of errors and uncertainty quantification
- Error propagation and least squares method
- Curve fitting and confidence intervals
- Introduction to Monte Carlo techniques

Part C: Computational Tools in High Energy Physics

- **ROOT Framework**
  - Introduction and basic structure
  - ROOT files: input/output, tree structures
  - Histograms and statistical tools
  - Graphs and curve fitting
  - Monte Carlo simulations and visualization

References:

Internal laboratory manuals and experiment-specific handouts will be provided as primary reference materials.

Paper Name: ***Condensed Matter Physics Lab***
Paper Code: **PHY521**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. To introduce students to a range of experimental techniques relevant to the study of physical properties in condensed matter systems.
2. To develop skills in accurate data collection, experimental setup, and handling of scientific instruments related to magnetism, spectroscopy, and material synthesis.
3. To foster an understanding of structure-property relationships through practical exposure to the synthesis and characterization of materials.
4. To train students in scientific reasoning through analysis of experimental results and comparison with theoretical models.
5. To enhance students' ability to document, interpret, and communicate scientific results effectively in a laboratory environment.

Course Description:

This laboratory course is designed to provide hands-on experience with experimental techniques essential in condensed matter physics. It covers fundamental and advanced experiments such as magnetic susceptibility, Curie temperature, heat capacity of solids, electrical analogs of crystal structures, nuclear magnetic resonance, optoelectronic properties of materials, and synthesis and characterization of solid-state materials including thin films. The course fosters the development of technical skills and analytical thinking to bridge the gap between theoretical understanding and practical application.

Course Outcomes (COs):

On successful completion of this course, students will be able to:

CO1: *Recall and define* the basic concepts and terminology related to magnetic, thermal, electrical, and structural properties of materials through laboratory-based experimentation.

CO2: *Explain* the working principles of instruments and experimental setups used for studying phenomena such as NMR, photo-resistance, and dielectric behavior in condensed matter systems.

CO3: *Apply* theoretical knowledge to conduct experiments involving thermal evaporation, magnetic susceptibility, and dispersion relations, and perform basic synthesis of materials.

CO4: *Analyze* experimental data, identify trends and anomalies, and draw inferences regarding material properties such as Curie temperature, heat capacity, and band structure.

CO5: *Evaluate* experimental techniques and results critically, assess the limitations of methods used, and propose improvements or alternative approaches for further investigation.

Course Content:

Experiment 1: Determination of susceptibility of a paramagnetic solution ($FeCl_3$/$MnSO_4$) by Quinck's Method.

Experiment 2: Determination of Curie temperature of Monel metal.

Experiment 3: Determination of Heat Capacities of Solids.

Experiment 4: Dispersion Relation in periodic electrical circuit, Study of electrical analogue mono-atomic and di-atomic chain.

Experiment 5: To determine nuclear g factor by using Nuclear Magnetic Resonance Spectroscopy.

Experiment 6: To study Current Voltage characteristic of a photo resistor: *CdS* as a function of wavelength by using a monochromator.

Experiment 7: Synthesis of Perovskite material using furnace and related characterization.

Experiment 8: Synthesis of metal thin films of (Cu/Ag/Al metal) on a glass substrate by using thermal evaporation technique and structural characterization through XRD.

Paper Name: ***Biomedical Image and Signal Processing Lab***
Paper Code: **PHY522**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

By the end of the course, students will be able to:

1. Provide hands-on experience with biomedical signal acquisition equipment such as EEG, ECG, pulse-oximeter, etc.
2. Train students in basic and advanced signal calibration and physiological data analysis.
3. Implement digital image processing techniques relevant to biomedical images.
4. Integrate signal and image processing concepts through real-world biomedical case applications.
5. Develop computational skills using MATLAB/Python for signal and image analysis.

Course Description:

This course offers a comprehensive exploration of the fundamental principles, instrumentation, and clinical applications of major medical imaging modalities and cutting-edge spectroscopic techniques vital for modern medical diagnostics. Students will delve into the underlying physics of image formation, master essential image processing techniques using MATLAB for quantitative analysis, and gain an understanding of how spectroscopic methods contribute to disease detection and monitoring. The curriculum emphasizes a blend of theoretical knowledge with practical skills essential for researchers and professionals in biomedical engineering and related fields.

Course Outcomes:

On successful completion of this course, students will be able to:

CO1: Calibrate and operate biomedical signal acquisition systems (EEG, ECG, pulse-oximeter, etc.).

CO2: Analyze physiological signals using time and frequency domain tools.

CO3: Apply basic image processing techniques like histogram equalization, gray-level transforms, and segmentation on medical images.

CO4: Implement and compare spatial and frequency domain filtering techniques in biomedical image contexts.

CO5: Develop integrated skills through mini-projects involving both signal and image processing.

Course Content

Bio-signal Processing

Experiment 1: To record ECG signals in different lead configurations and extract heart rate and rhythm characteristics.

Experiment 2: To acquire multichannel EEG data and perform basic noise filtering and analysis.

Experiment 3: To measure and analyze SpO_2 and pulse rate under different physiological conditions.

Experiment 4: To measure and analyze SpO_2 and pulse rate under different physiological conditions.

Experiment 5: To measure systolic and diastolic blood pressures using both manual and digital methods.

Image Processing

Experiment 6: To apply linear and non-linear transformations on grayscale images and enhance contrast in low-resolution images using histogram equalization.

Experiment 7: To smooth or sharpen images using mean, Gaussian, Laplacian, and analyze the effect of Fourier-based filters for noise reduction and feature enhancement.

Experiment 8: To implement thresholding, edge detection (Sobel, Canny), and region-based segmentation.

Experiment 9: Students will carry out a small project involving analysis of biomedical signal and associated medical image (e.g., ECG + echocardiogram, EEG + brain scan).

References:

1. Manuals will be supplied for the instrument-based experiments.
2. Willis J. Tompkins (Editor), *Biomedical Digital Signal Processing*, Prentice-Hall, 1993.
3. Rangayyan, R. M., *Biomedical Signal Analysis*, Wiley-IEEE Press, 2nd Edition, 2015.
4. S. Suresh, *Biomedical Signal and Image Processing*, CRC Press, 2023.
5. Gonzalez, R. C., & Woods, R. E., *Digital Image Processing*, Pearson Education, 4th Edition, 2018.
6. K. N. Chatterjee, *Biomedical Instrumentation Systems*, Delmar Cengage Learning, 2008.
7. Acharya U Rajendra, et al., *Biomedical Signal and Image Processing Using MATLAB*, CRC Press, 2007.

Paper Name: ***Computational Astrophysics***
Paper Code: **PHY523**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

By the end of the course, students will be able to:

1. Understand core numerical and statistical methods commonly used in astrophysical research.
2. Develop practical skills in implementing computational algorithms using Python and relevant libraries.
3. Analyse astronomical data sets using statistical and computational techniques.
4. Explore selected applications of computational methods to key problems in astrophysics (stellar systems, exoplanets, CMB, galaxy spectra, gravitational waves).
5. Gain familiarity with publicly available astronomical data sources and scientific data analysis pipelines.

Course Description:

This Discipline Specific Elective course introduces essential computational techniques used in modern astrophysics. Emphasis is placed on practical numerical methods, data analysis, and basic modelling relevant to astrophysical problems. Students will develop hands-on skills in scientific programming (Python-based), numerical algorithms, and statistical data analysis. The course also introduces selected applications in astrophysical contexts.

Course Outcomes:

CO1: Explain the principles of numerical computation and statistical inference methods relevant to astrophysical data analysis.

CO2: **Implement** numerical algorithms (root finding, integration, ODE solvers, Fourier analysis) to solve representative computational problems in astrophysics.

CO3: **Apply** statistical analysis and parameter inference techniques to observational and simulated astrophysical data sets.

CO4: **Analyze** real astronomical data to extract key physical parameters and test astrophysical models.

CO5: **Demonstrate** proficiency in using Python-based tools and publicly available data to perform computational investigations in contemporary astrophysics.

Course Content

Module 1: Foundations of Numerical Computation *(8 Hours)*

Overview of computational methods in astrophysics, Data handling and basic operations: data sorting, large data sets, Numerical solutions of algebraic equations (Root finding: Bisection, Newton-Raphson), Numerical differentiation and integration (Trapezoidal, Simpson's rule), Interpolation and extrapolation.

Module 2: Numerical Methods for Differential Equations *(10 Hours)*

Solving ODEs: Euler, Runge-Kutta methods (2nd and 4th order), Brief introduction to PDE solvers (Finite differences; basic concept of stability), Application examples: stellar structure equations, simple fluid flow.

Module 3: Basic Linear Algebra for Astrophysics *(10 Hours)*

Matrix operations: inversion, LU decomposition, Singular Value Decomposition (SVD) and its application in astrophysics, Least-squares fitting and model fitting in astrophysics

Module 4: Statistics & Inference Methods *(10 Hours)*

Probability distributions: Gaussian, Poisson, Binomial, Random number generation and testing (Kolmogorov-Smirnov test, Chi-squared test), Parameter inference: Bayesian inference basics, least-squares in Bayesian framework, Basic exposure to Markov Chain Monte Carlo methods (conceptual introduction only)

Module 5: Fourier Techniques & Timing Analysis *(10 Hours)*

Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Power spectrum analysis Cross-spectrum, brief mention of wavelets (conceptual level), Application examples: pulsar timing, variability of AGN, time series in astrophysics.

Module 6: Selected Applications in Computational Astrophysics *(15 Hours)*

Determining parameters of Extra-Solar planets, Main sequence fitting of a star cluster, Statistics of the Cosmic Microwave Background Radiation, Galaxy Spectral Fitting, Obtaining parameters of the Hulse-Taylor Binary System, Modelling gravitational waveforms (optional).

References:

1. Bodenheimer et al., *Numerical Methods in astrophysics: An Introduction*, Taylor & Francis, 2007.
2. P. Hellings, *Astrophysics with a PC: An Introduction to Computational Astrophysics*, Willmann-Bell, 1994.
3. P. R. Bevington & K.K. Robinson, *Data Reduction and Error Analysis for Physical Sciences*, McGraw-Hill, 2003.
4. A. Papoulis, S. U. Pillai, *Probability, Random Variables and Stochastic Processes*, McGraw Hill Education; 4th edition, 2017.
5. D. E. Knuth, *The Art of Computer Programming, vol.1: fundamental algorithms*, Addison-Wesley, 3rd edition, 1997.
6. Forman S. Acton, *Numerical Methods that (usually) Work*, The Mathematical Association of America, 1997.
7. Ronald N. Bracewell, *The Fourier Transforms and its Applications*, McGraw-Hill Inc., 1978.
8. Bayesian methods in Cosmology: Roberto Trotta, online notes, https://arxiv.org/pdf/1701.01467.pdf.

Paper Name: ***Advanced Photonics Lab***
Paper Code: **PHY524**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. **Understand** advanced optical principles and photonics concepts for laboratory and simulation-based experiments.
2. **Apply** computational tools like MATLAB and FEM to model and simulate optical systems.
3. **Design** and perform experiments to investigate properties of lasers, optical fibers, and thin films.
4. **Analyze** experimental data to extract physical insights related to optical devices and sensors.
5. **Evaluate** performance parameters of optical systems to identify optimization strategies in design and application.

Course Description:

Advanced Photonics Lab offers hands-on training in modern optical experimentation and simulation techniques. The course covers fundamental and advanced topics including Fourier optics, geometric phase, and holography. Students will explore fiber-optic-based surface plasmon resonance (SPR) sensors, optical signal processing using MATLAB, and the synthesis and characterization of metal thin films. Emphasis is placed on integrating computational tools with experimental setups to investigate laser parameters, optical fiber sensors, and optoelectronic devices. The course prepares students to design, simulate, and analyze real-world photonic systems using advanced instrumentation and software platforms.

Course Outcomes:

CO1 – Understand the working principles of Fourier optics, geometric phase, and holography, and their applications in optical experimentation.

CO2 – Perform and analyze surface plasmon resonance (SPR) simulations on thin-film-coated optical fiber sensors and interpret optical spectra using MATLAB.

CO3 – Synthesize thin metal films using thermal evaporation techniques and **characterize** their crystalline structures using XRD.

CO4 – Evaluate the performance characteristics of laser beams (peak power and beam divergence), solar cells, and photoresistors using experimental data.

CO5 – Design and conduct experiments using spatial light modulators, dielectric constant measurements, and fiber-optic-based sensors (pressure/turbidity/displacement), integrating computational and experimental approaches.

Course Content

Experiment 1

Fourier Optics experiment – Spatial frequency filtering

Experiment 2

Geometric Phase of light

Experiment 3

Simulation on thin film coated optical fiber-based surface plasmon resonance (SPR) refractive index sensor

Experiment 4

Optical Spectrum analysis using MATLAB

Experiment 5

Analysis of optical signal using Fourier Transform Method

Experiment 6

To synthesize of metal thin films of (Al/Ag metal) on a glass substrate by using thermal evaporation technique under high vacuum. Study of crystalline structure of metal thin films by using X-ray Diffraction technique.

Experiment 7

Determine the peak power and beam divergence of Laser beam.

Experiment 8

Study of Laser holography.

Experiment 9

Experiments with Spatial Light modulator

Experiment 10

Measurements of Dielectric constant of a specimen (liquid) at high frequency.

Experiment 11

To study I-V characteristic of Solar Cell and determine maximum power output from the I-V curve.

Experiment 12

To study Current Voltage characteristic of a photo resistor: *CdS* as a function of wavelength by using a monochromator.

Experiment 13

Study of optical fiber-based pressure/turbidity/displacement sensor

Reference Books

1. **Joseph W. Goodman**, *Introduction to Fourier Optics*, McGraw-Hill
2. **Bahaa E. A. Saleh & Malvin Carl Teich**, *Fundamentals of Photonics*, Wiley
3. **P. Hariharan**, *Basics of Interferometry*, Academic Press
4. **Online Simulation Resources**:
   i. OpticsBench.com
   ii. MATLAB Fourier optics toolboxes/tutorials
   iii. SLM experiment kits and guides from **Thorlabs** and **HamamatsuHomayoon Oraizi**, *Electromagnetic Simulation Using the FDTD Method*, Wiley

5. **Jiri Homola**, *Surface Plasmon Resonance Based Sensors*, Springer
6. **B.P. Pal**, *Guided Wave Optical Components and Devices: Basics, Technology, and Applications*, Elsevier
7. **Journal articles**:
   i. *IEEE Sensors Journal*
   ii. *Optics Express* (for SPR and fiber sensors simulation with MATLAB/COMSOL)

8. **M. A. Gibilisco**, *Optical Physics for Engineers*, McGraw-Hill
9. **R. G. Lyons**, *Understanding Digital Signal Processing*, Pearson
10. **MathWorks Documentation**: https://www.mathworks.com/help/ (MATLAB for optical simulations)
11. **K.L. Chopra**, *Thin Film Phenomena*, McGraw-Hill
12. **O.S. Heavens**, *Optical Properties of Thin Solid Films*, Dover
13. **Cullity & Stock**, *Elements of X-Ray Diffraction*, Pearson
14. **Practical guides from equipment manufacturers**: **Hind High Vacuum**, **Edwards**, or **Denton Vacuum**
15. **William T. Silfvast**, *Laser Fundamentals*, Cambridge University Press
16. **A. E. Siegman**, *Lasers*, University Science Books
17. **P. Hariharan**, *Optical Holography: Principles, Techniques and Applications*, Cambridge
18. **Laboratory guides** from **Thorlabs**, **Edmund Optics**

General Lab References

1. **M.N. Avadhanulu & P.G. Kshirsagar**, *A Textbook of Engineering Physics: Practical*, S. Chand
2. **S.O. Kasap**, *Principles of Electronic Materials and Devices*, McGraw-Hill
3. **Online resources**:
   i. **Thorlabs Application Notes**: www.thorlabs.com
   ii. **SPIE Digital Library**
   iii. **COMSOL Blog** (for modeling optical sensors and materials)

Paper Name: **Nano-Materials Lab**
Paper Code: **PHY525**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. To provide exposure to the synthesis of nanostructured materials and thin films using thermal evaporation and other high-vacuum techniques.
2. To impart knowledge about advanced characterization tools such as X-ray diffraction (XRD) and UV-Vis spectroscopy for analyzing nanomaterials.
3. To develop understanding of functional nanomaterials through experiments involving solar cells, photoresistors, and dielectric materials.
4. To enhance practical skills in measuring and interpreting electrical and optical properties at the nanoscale.
5. To promote analytical thinking for drawing correlations between experimental results and theoretical principles in nanoscience.

Course Description:

This laboratory course introduces students to fundamental and advanced experimental techniques used in the field of nanomaterials. Through hands-on experiments, students will learn methods of synthesis of metallic and polymeric nanostructures, thin film deposition, optical and structural characterization, and the study of key properties such as dielectric behavior, surface plasmon resonance, and photovoltaic response. Emphasis is placed on understanding the nanoscale phenomena, material behavior, and their applications in modern devices and technologies.

Course Outcomes (COs):

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

CO1: *Recall and define* key concepts related to nanomaterials synthesis, thin film deposition, and optical/electrical characterization techniques.

CO2: *Explain* the principles behind experimental methods such as surface plasmon resonance, dielectric constant measurement, and solar cell performance.

CO3: *Apply* standard techniques to synthesize and characterize nanoscale materials like metals, perovskites, and polymers, using instruments such as furnaces, vacuum coating units, and spectrometers.

CO4: *Analyze* experimental data from I-V characteristics, UV-Vis spectra, and temperature-dependent dielectric behavior to interpret material properties and device performance.

CO5: *Evaluate* the efficiency, reliability, and limitations of nanomaterials-based devices and experiments, and propose enhancements for materials design or measurement approaches.

Course Content:

Experiment 1: To synthesize of metal nano grain sized thin films of (Al/Ag metal) on a glass substrate by using thermal evaporation technique under high vacuum. Study of crystalline structureof metal thin films by using X-ray Diffraction technique.

Experiment 2: To synthesize the very thin metal film [Ag/Al] [< 5nm] on a glass substrate by using thermal evaporation technique under high vacuum and observe the surface Plasmon resonance phenomena through UV-vis spectrometer.

Experiment 3: To study I-V characteristic of Solar Cell and determine maximum power output from the I-V curve.

Experiment 4: To measure dielectric constant of a given ferroelectric material: $BaTiO_3$ and determination of Curie temperature (Tc) from temperature dependent di-electric constant data.

Experiment 5: To study Current Voltage characteristic of a photo resistor: *CdS* as a function of wavelength by using a monochromator.

Experiment 6: Synthesis of Perovskite material using furnace and related characterization.

Experiment 7: Synthesis of Polymer thin film and related characterization.

SKILL ENHANCEMENT COURSES (SEC) OFFERED BY DEPARTMENT OF PHYSICS

Paper Name: **PHYSICS LAB I**
Paper Code: **PHY455**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. To introduce students to key experimental setups that illustrate fundamental physical constants, quantum effects, and semiconductor properties.
2. To enable understanding of measurement techniques for material parameters such as energy band gap, Hall coefficient, and magneto-resistance.
3. To develop familiarity with optical and magnetic instrumentation through practical demonstrations of phenomena like photoelectric effect and electron focusing.
4. To provide training in designing, assembling, and testing passive and active filters using basic electronic components.
5. To promote the ability to connect experimental observations with theoretical principles, enhancing problem-solving and analytical skills.

Course Description:

This lab course is designed to provide undergraduate students with practical exposure to foundational experiments in modern physics, semiconductor physics, and electronic circuits. The experiments aim to reinforce theoretical knowledge by exploring the quantum nature of light, charge-to-mass ratio of electrons, band structure in semiconductors, magneto-transport phenomena, and electronic filter design using both passive and active elements. Through hands-on work with optical, magnetic, and electronic setups, students develop experimental skills and critical thinking needed in core areas of physics.

Course Outcomes (COs):

On successful completion of the course, students will be able to:

CO1: **Recall and define** key concepts related to quantum mechanics, semiconductor physics, and electrical circuit behavior in the context of physical measurements.

CO2: **Explain** the working principles of experiments such as the photoelectric effect, Franck-Hertz experiment, Hall effect, and filter circuits.

CO3: **Apply** theoretical knowledge to perform experiments involving semiconductor characterization, magneto-resistance, and photo-response using modern lab equipment.

CO4: **Analyze** experimental data to determine physical constants like Planck's constant, e/m ratio, and band gap, and interpret the outcomes in relation to theoretical expectations.

CO5: **Evaluate** the design and frequency response of passive and active filters using both qualitative and quantitative techniques, and assess the significance of physical parameters obtained from various experimental modules.

Course Content

Experiment 1: Determine Plank's Constant using photo-cell with filters for different light wave length (λ). Also verify the inverse square law.

Experiment 2: Determination of e/m of electrons by magnetic focusing method.

Experiment 3: To determine the energy band gap of Ge crystal by Four Probe Method.

Experiment 4: Determine temperature dependence of Hall coefficient of n-type and p-type semiconductor material.

Experiment 5: Study of Current Voltage characteristic of a *CdS*, a photo resistor as a function of Intensity using optical bench.

Experiment 6: Study the variation of Magneto-resistance of *n-type*/*p-type* semiconductor material.

Experiment 7: Verification of Bohr's atomic theory by Franck Hertz Experiment.

Experiment 8:

i. Design and study frequency response of Passive filters (a) High pass (b) Low pass (c) Notch filters. (d) Wide Band-pass Filter.

ii. Design and study frequency response of 1st order Active filters (use OPAMP as active element) (a) High pass (b) Low pass (c) Band pass (d) Band reject (e) Narrow band pass filters etc.

Paper Name: ***Physics Lab II***
Paper Code: **PHY469**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. To introduce fundamental and applied concepts of optical interference, polarization, and fiber optics through structured experiments.
2. To expose students to the working principles and characteristics of various optoelectronic devices such as solar cells, photodiodes, and LDRs.
3. To provide practical understanding of digital electronics, focusing on sequential logic components like flip-flops, counters, and registers.
4. To enable students to correlate experimental results with theoretical models, improving analytical and troubleshooting skills.
5. To develop students' abilities to interpret timing diagrams and evaluate circuit behavior in response to real-time input signals.

Course Description:

This lab course offers hands-on training in advanced optics and digital electronics. Students explore optical phenomena like interference, polarization, and optical fiber transmission, as well as electrical characteristics of optoelectronic devices. In the digital domain, learners engage with sequential logic by designing and analyzing circuits such as flip-flops, counters, and shift registers. The course bridges theoretical physics with real-world application, enhancing students' analytical thinking and practical proficiency in both optics and electronics.

Course Outcomes (COs):

On successful completion of this course, students will be able to:

CO1: **Recall and define** basic principles of interference, polarization, fiber optics, and digital electronics relevant to the lab experiments.

CO2: **Explain** the functional behavior of optoelectronic devices and digital components like flip-flops and shift registers.

CO3: **Apply** experimental methods to investigate refractive index, numerical aperture, and V-I characteristics of light-sensitive devices using laser and optical fiber setups.

CO4: **Analyze** timing diagrams and logic behavior of sequential circuits including counters and master-slave configurations.

CO5: **Evaluate** the performance and response of both optical and digital systems, drawing conclusions from experimental results and comparing them with theoretical predictions.

Course Content

Experiment 1: Determination of refractive index of a glass plate using Laser source based on Michelson interferometry technique.
Experiment 2: Study characteristic of Optoelectronic devices.
i) Study of response characteristic of a solar-cell using Laser light.
ii) Study of V-I characteristic of LDR. Also study the response characteristic of LDR.
iii) Study of V-I characteristic and response characteristic of a phototransistor.
iv) To study the response characteristic of a photodiode.
v) To study response characteristic of an opto-coupler.
Experiment 3: To study polarization properties of light and verify the Malu's Law using Laser source.
Experiment 4: Experiments using Optical Fiber:
i) Determination of numerical aperture of an Optical fiber.
ii) Study the bending and splice loss in an optical fiber.
Experiment 5: To build Flip-Flop (RS, Clocked RS, D-type and JK) circuits using NAND gates. To build JK Master-slave flip-flop using Flip-Flop ICs.
Experiment 6: To build a 4-bit Counter using D-type/JK Flip-Flop ICs and study timing diagram.
Experiment 7: To make a 4-bit Shift Register (serial and parallel) using D-type/JK Flip-Flop ICs.

MULTIDISCIPLINARY ELECTIVE COURSES (MDE) OFFERED BY DEPARTMENT OF PHYSICS

Paper Name: *AI Essentials – Concept and Applications* (Semester II)

Paper Code: PHY470
LTP: 3-0-1

Course Objectives:

1. To introduce key concepts and methods in Artificial Intelligence.
2. To develop practical coding skills for implementing AI algorithms.
3. To explore applications of AI in Physics and scientific data analysis.
4. To introduce basics of Natural Language Processing for scientific text analysis
5. To design simple AI models and evaluate their effectiveness on real data.

Course Description:

This course introduces foundational concepts of Artificial Intelligence and its applications with a focus on machine learning, neural networks, and natural language processing. Students will develop both conceptual and practical understanding of AI methods and explore their applications in physics, scientific computing, and data analysis. Hands-on exercises with Python-based tools will support applied learning.

Course Outcomes:

CO1: Recall fundamental concepts, terminologies, and the scope of Artificial Intelligence across various domains.

CO2: Interpret the structure and functioning of basic AI models, algorithms, and techniques.

CO3: Apply appropriate AI methods to solve domain-related problems using suitable tools and techniques.

CO4: Analyze data characteristics and algorithmic performance to choose suitable AI approaches.

CO5: Evaluate AI systems for effectiveness, fairness, and reliability in practical contexts.

CO6: Develop and Demonstrate an AI-based tools for solving domain-specific problems using Python.

Course Content

Module 1: Introduction to AI and Machine Learning *(5 Hours)*

Overview and evolution of AI, Types of learning: Supervised, Unsupervised, Reinforcement, AI workflow: Data → Model → Training → Testing, Case studies in AI for Science and Engineering

Module 2: Data Handling and Preprocessing *(4 Hours)*

Types of data: numerical, categorical, text, Handling missing values and noise, Feature selection vs. extraction, Data scaling, normalization, standardization, Splitting datasets: train/test/validation and cross-validation

Module 3: Machine Learning Algorithms *(12 Hours)*

Linear and Logistic Regression, K-Nearest Neighbors (KNN), Decision Trees and Random Forest, K-Means Clustering and Hierarchical Clustering, Evaluation metrics: Confusion Matrix, Accuracy, Precision, Recall, F1 Score, ROC-AUC

Module 4: Neural Networks and Deep Learning *(10 Hours)*

Perceptron and Multi-Layer Perceptron (MLP), Backpropagation concept, Overview of CNNs and RNNs (without derivation), Activation functions, loss functions (overview), Overfitting, dropout, regularization (concepts only), Applications in Physics: signal classification, simulations

Module 5: Natural Language Processing and Ethical AI *(10 Hours)*

Basics of NLP: tokens, stemming, lemmatization, stopwords, Vectorization: Bag of Words, TF-IDF, Simple text classification (e.g., categorizing abstracts or reports), Ethics in AI: bias, transparency, black-box risks, Interpreting models and responsible AI use in science

Module 6: Laboratory (Hands-on Practicals)

Tools: Python, Jupyter Notebook, NumPy, pandas, scikit-learn, matplotlib, Keras, NLTK/spaCy

Sample Exercises:

1. Exploratory data analysis and visualization on Physics datasets
2. Implementing Linear Regression on experimental data
3. KNN and Decision Tree classifiers for data categorization
4. Clustering of noise/signal patterns using K-means
5. Implementing a simple Perceptron model
6. NLP task: keyword extraction and classification from research abstracts

References:

1. Stuart Russell & Peter Norvig, *Artificial Intelligence: A Modern Approach*
2. Aurélien Géron, *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow*
3. Steven Bird, *Natural Language Processing with Python (NLTK Book)*
4. Research articles and datasets from arXiv, Kaggle, and NASA Open Data

Paper Name: ***Numerical Techniques in Science***
Paper Code: **PHY471**
Credit: **4**
LTP: **0-0-4**

Course Objectives:

By the end of the course, students will be able to:

1. Develop proficiency in using scientific computing tools and programming languages for solving numerical problems in science and engineering.
2. Apply matrix methods, numerical integration, and differential equation solvers to analyse and model physical and mathematical systems.
3. Implement Monte Carlo methods and probabilistic techniques for numerical estimation and error analysis.
4. Perform statistical analysis and hypothesis testing on experimental and simulated data, including exploratory data analysis and visualization.
5. Understand and apply advanced statistical methods such as Bayesian inference and principal component analysis (PCA) to multivariate data sets.

Course Description:

This multidisciplinary elective course introduces M.Sc. Physics students to the essential numerical and statistical techniques used in modern scientific research. Blending computational physics, numerical analysis, and data science, the course equips students with practical skills to model physical systems, solve complex equations, and analyse experimental data. Emphasis is placed on the use of scientific programming tools (with Python as the primary platform), covering matrix methods, numerical integration, differential equation solvers, and Monte Carlo techniques. In parallel, students explore foundational and advanced statistical methods, including exploratory data analysis, hypothesis testing, and Bayesian inference. Designed for physicists aiming to engage with data-intensive science and computational modelling, this course prepares students for advanced research, interdisciplinary collaborations, and industry roles in scientific computing, quantitative research, and data-driven fields.

Course Outcomes:

CO1: Explain the principles and numerical techniques used in solving linear systems, differential equations, and integral problems in scientific computing.

CO2: Implement numerical algorithms (matrix methods, ODE solvers, Monte Carlo integration) to model and analyse physical systems using programming tools such as Python.

CO3: Analyse the stability, accuracy, and convergence of numerical methods, and **evaluate** their effectiveness in modeling real-world physical systems.

CO4: Apply descriptive statistics, hypothesis testing, and exploratory data analysis (EDA) to interpret experimental and simulated data in scientific research.

CO5: Utilize advanced statistical techniques such as Bayesian inference and principal component analysis (PCA) to perform multivariate data analysis and gain scientific insights.

Course Content

Module 1: Introduction & Computational Tools *(8 Hours)*

Review of Programming Languages/Tools: Python (preferred), or Mathematica/Matlab/Scilab; Introduction to libraries useful for scientific computing: NumPy, SciPy, Matplotlib (if Python is used); Random number generation & pseudo-randomness (NumPy Random module, concept of pseudo-randomness, PRNG).

Module 2: Linear Algebra Methods *(10 Hours)*

Solution of linear systems: Gauss Elimination, Gauss-Seidel Iterative Method; Matrix operations: Matrix Inverse, Matrix Diagonalization, Eigenvalues and Eigenvectors.

Module 3: Numerical Integration & Monte Carlo Methods *(10 Hours)*

Quadrature methods: Trapezoidal Rule, Simpson's Rule; Monte Carlo Integration: Basic Monte Carlo estimation of integrals, Rejection Sampling (optional); Error estimation using probabilistic methods; Applications to experimental and simulated data.

Module 4: Numerical Solution of Differential Equations *(10 Hours)*

First order ODEs: Euler Method, Modified Euler Method, Runge-Kutta 2nd Order; Applications: radioactive decay, Newton's law of cooling, population models; Second order ODEs: Runge-Kutta 4th Order, Harmonic oscillator (undamped, damped, forced — focus on physical intuition and numerical behaviour); Finite Difference Method for 2nd order differential equation: Boundary value problems, Concept of stability and convergence.

Module 5: Module 5: Statistical Analysis and Data Science Methods *(12 Hours)*

Descriptive Statistics: Measures of central tendency and dispersion (Mean, Median, Variance, Standard Deviation); Probability Distributions: Binomial, Poisson, Gaussian; Confidence Intervals & Error Bars: Concept and practical calculation, Visualization; Regression and Correlation: Correlation coefficients, Simple Linear Regression; Hypothesis Testing: Chi-Square Test, t-Test, ANOVA; Goodness of Fit: Application to fitting models to data, Visualization of fits; Outlier Detection Techniques: Z-score method, Box plots, visual techniques; Exploratory Data Analysis (EDA): Box plots, QQ-plots, Normality checks.

Module 6: Advanced Statistical & Probabilistic Methods *(10 Hours)*

Bayesian Inference (Conceptual only): Bayes' Theorem, Prior/Posterior estimation, Markov Chain Monte Carlo (Conceptual understanding only); Multivariate Statistics: Covariance matrix, Principal Component Analysis (PCA), Factor analysis (conceptual, no deep computation required)

References:

1. T. Pang**,** *An Introduction to Computational Physics*, Cambridge University Press, 2nd Edition, 2006.
2. Rubin H. Landau, Manuel J. Paez, Cristian C. Bordeianu, *Computational Physics: Problem Solving with Python*, Wiley-VCH, 3rd Edition, 2021.
3. John C. Butcher, *Numerical Methods for Ordinary Differential Equations*, Wiley, 3rd Edition, 2016.
4. William Navidi, Statistics for Engineering and the Scientists, McGraw-Hill Education, 4th Edition, 2014.
5. Allen B. Downey, *Think Stats: Exploratory Data Analysis in Python*, O'Reilly Media, 2nd Edition, 2014.

Paper Name: ***Unmasking Bio-Signals***
Paper Code: **PHY472**
Credit: **4**
LTP: **3-0-1**

Course Objectives:

By the end of the course, students will be able to:

1. Understand the physical principles underlying bio-signal generation in the human body.
2. Explore the instrumentation used in acquiring and analyzing bio-signals.
3. Develop practical skills in acquiring, filtering, and interpreting bio-signals like ECG, EEG, EMG, etc.
4. Apply basic signal processing techniques to analyze time- and frequency-domain properties of bio-signals.
5. Investigate real-world applications of bio-signal analysis in healthcare, neuroscience, and medical diagnostics.

Course Description:

This multidisciplinary elective course introduces M.Sc. Physics students to the fascinating world of bio-signals—electrical, mechanical, and chemical manifestations of biological processes. With an emphasis on the physics behind signal generation, acquisition, and interpretation, the course blends fundamental concepts from physiology, instrumentation, and signal processing. Students will gain hands-on experience with real and simulated bio-signals such as ECG, EEG, EMG, and others through lab sessions and case-based discussions. Designed for physicists with an eye toward biomedical applications, this hybrid course bridges the gap between physics and life sciences, preparing students for research and industry roles in biomedical engineering, neuroscience, and medical physics.

Course Outcomes:

CO1: **Explain** the origins and characteristics of major bio-signals (ECG, EEG, EMG, etc.) using physical and physiological principles.

CO2: **Analyze** the principles and components of bio-signal acquisition systems, including electrodes, amplifiers, filters, and noise reduction techniques.

CO3: **Interpret** the time- and frequency-domain characteristics of bio-signals using signal analysis tools grounded in physics.

CO4: **Apply** signal processing techniques (filtering, Fourier analysis, etc.) to extract meaningful information from raw bio-signals.

CO5: **Evaluate** the implications of signal artifacts and distortions, and suggest methods for improving signal fidelity.

CO6: **Demonstrate** proficiency in handling bio-signal data using software tools such as MATLAB or Python.

Course Content

Module 1: Introduction to Bio-signals and Physiological Foundations *(8 Hours)*

Overview of physiological signal generation: electrical, mechanical, and chemical origins. Action potentials: resting potential, depolarization, repolarization, Excitable tissues: nerve and muscle physiology. Introduction to key bio-signals: ECG, EEG, EMG, EOG, Signal characteristics: amplitude, frequency, bandwidth, variability, Classification: periodic vs aperiodic, evoked vs spontaneous.

Module 2: Bio-signal Acquisition and Instrumentation *(10 Hours)*

Electrodes: surface, needle, microelectrodes – types and properties. Lead configurations: bipolar and unipolar systems (e.g., 12-lead ECG). Instrumentation amplifiers, differential amplifiers, isolation amplifiers. Filters: low-pass, high-pass, band-pass, notch – analog and digital. Sources of noise and interference: motion artifact, power line interference. Signal conditioning: amplification, impedance matching, shielding.

Module 3: ECG, EEG, EMG – Signal Features and Clinical Insight *(10 Hours)*

ECG: Cardiac conduction system, wave components (P, QRS, T), arrhythmias. EEG: Brain rhythms (alpha, beta, delta, theta), sleep patterns, epilepsy markers. EMG: Muscle activation patterns, motor unit potentials, neuromuscular disorders. Physiological variability and its significance. Overview of clinical instrumentation: ECG monitors, EEG caps, EMG probes. Biomedical ethics in signal monitoring.

Module 4: Signal Processing Techniques for Bio-signals *(10 Hours)*

Discrete representation of bio-signals: sampling and quantization. Time-domain analysis: peak detection, envelope extraction. Frequency-domain analysis: Fourier transform, power spectral density. Time-frequency analysis: Short-Time Fourier Transform (STFT), Wavelet Transform.

Signal denoising: moving average, adaptive filtering. Feature extraction and basic pattern recognition. Introduction to machine learning concepts in biosignal classification.

Module 5: Bio-signal Applications and Integration with Medical Physics *(7 Hours)*

Clinical case studies using ECG, EEG, and EMG data. Use of bio-signals in medical imaging (e.g., gating in MRI/CT). Applications in brain-computer interface (BCI), prosthetic control. Role in radiotherapy planning and monitoring (e.g., respiratory gating). Future directions: wearable sensors, telemedicine, AI in biosignals. Interdisciplinary research opportunities.

Practical Module: Bio-signal Acquisition and Analysis Lab *(30 Lab Hours, spread across semester)*

1. ECG and EEG signal acquisition using real instrumentation
2. Use of MATLAB for signal visualization and preprocessing
3. Implement filtering and artifact removal on sample datasets
4. Feature extraction and simple classification (e.g., arrhythmia detection)
5. Mini-project: Case study involving signal analysis and interpretation

References:

1. Rangaraj M. Rangayyan, *Biomedical Signal Analysis: A Case-Study Approach*, Wiley-IEEE Press, 2nd Edition, 2015.
2. John G. Webster (Editor), *Medical Instrumentation: Application and Design*, Wiley, 4th Edition, 2009.
3. Willis J. Tompkins (Editor), *Biomedical Digital Signal Processing: C-Language Examples and Laboratory Experiments for ECG and EMG*, Prentice-Hall, 1993.
4. Leslie Cromwell, Fred J. Weibell, Erich A. Pfeiffer, *Biomedical Instrumentation and Measurements*, Prentice-Hall, 2nd Edition, 2011.
5. Eugene N. Bruce, *Biomedical Signal Processing and Signal Modeling*, Wiley, 2001.
6. D.C. Reddy, *Biomedical Signal Processing – Principles and Techniques*, Tata McGraw-Hill Education, 2005.
7. Open-Source Databases and Tools:

   PhysioNet – https://physionet.org

   MNE-Python – https://mne.tools

   BioSPPy – https://biosppy.readthedocs.io

Paper Name: **INTERNSHIP**
Paper Code: **PHY503**
Credit: **2**
LTP: 0-0-2

Course Objectives:

1. Expose students to real-world applications of physics in industry or research settings.
2. Develop professional skills and networking opportunities.
3. Enhance understanding of collaborative research processes.
4. Facilitate the application of theoretical knowledge in practical environments.

Course Outcomes:

CO1: Recall and apply fundamental and advanced concepts from the domain to identify and define real-world problems during the internship.

CO2: Explain the methodologies, techniques, and tools utilized in the internship, relating them to theoretical knowledge gained in coursework.

CO3: Apply technical, computational, and experimental skills to contribute effectively to the projects or tasks assigned during the internship.

CO4: Analyze the effectiveness of implemented methods or tools, identifying challenges, limitations, and opportunities for improvement.

CO5: Evaluate the societal, ethical, and environmental implications of the internship work, ensuring adherence to professional standards and practices.

CO6: Design and deliver a comprehensive internship report or presentation, effectively communicating the work, findings, and their significance.

Catalogue Description:

Direct Hands-on training in Industry/ Research Institutes, exposure to real world scenario which is helpful for employability. Students will undertake a significant experimental learning opportunity, typically with a company, non-profit, governmental or community-based organization. The internship represents an educational strategy that links classroom learning and student interest with the acquisition of knowledge in an applied work setting. Through direct observation, reflection and evaluation, students gain an understanding of the internship site's work, mission and audience as well as the organization's position in the industry.

Paper Name: ***Dissertation I***
Paper Code: **PHY504**
Credit: **6**
LTP: 0-0-6

Course Objectives:

1. Encourage students to engage with current research trends in physics.
2. Develop presentation and communication skills through seminar participation.
3. Foster critical thinking and discussion on contemporary issues in physics.
4. Promote peer feedback and collaborative learning.

Course Outcomes:

CO1: Recall key concepts, principles, and recent advancements in physics and applied physics from contemporary research.

CO2: Explain the methodologies, theoretical frameworks, and experimental techniques used in recent research in physics and applied physics.

CO3: Apply critical thinking to evaluate the relevance and implications of recent research findings in solving real-world problems.

CO4: Analyze contemporary research papers and synthesize information to identify trends, challenges, and potential research opportunities.

CO5: Evaluate the societal, ethical, and technological impact of contemporary research in physics and applied physics.

Course Description:

In this course unit, students will get introduced to some contemporary fields of physics and applied physics topics which will lead to their dissertation thesis. They will learn to select a particular valid problem, working on the methodology, evaluate the result, and draw the right conclusions from it. Finally, they will be encouraged to give regular seminar on their understandings and findings which will be helpful to improve their oral communication skill. This is something where there is no bounded syllabus and students can work in their area of choice.

Paper Name: **DISSERTATION**
Paper Code: **PHY513**
Credit: **10**
LTP: 0-0-10

Course Objectives:

1. Oversee the execution of research projects in various fields of physics.
2. Enhance students' skills in data analysis and interpretation.
3. Guide students in presenting their research findings effectively.
4. Promote ethical considerations and standards in research.

Course Outcomes:

1. **CO1: Recall** and apply foundational and advanced concepts from the subject domain to define research objectives and explore innovative ideas.

2. **CO2: Explain** the existing literature and methodologies in the chosen research area, identifying gaps and opportunities for further study.

3. **CO3: Apply** appropriate experimental, computational, and analytical techniques to collect, analyze, and interpret data relevant to the research objectives.

4. **CO4: Critically** analyze results and interpret findings to validate hypotheses, considering the accuracy, reproducibility, and limitations of the research.

5. **CO5: Evaluate** the societal, ethical, and environmental implications of the research, ensuring compliance with scientific ethics and professional standards.

6. **CO6: Design and deliver** a comprehensive dissertation report, including well-structured documentation, data visualization, and effective oral presentations.

Catalogue Description:

In this course unit, students will get introduced to different fields of research, and how to do it in a very basic form. They will learn to select a particular valid problem, working on the methodology, Evaluate the result, and draw the right conclusions from it. This is something where there is no bounded syllabus and students can work in their area of choice.