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: 2024-25

Program Outcome for M.Sc. (Physics)

PO1	**Mastery of Advanced Physics Principles**	Apply advanced theoretical knowledge of physics principles and concepts to solve complex problems and challenges.
PO2	**Precision in Scientific Practice**	Demonstrate accuracy and precision in scientific inquiry, including the critical evaluation of theories, methodologies, and applications in both pure and applied sciences.
PO3	**Expertise in Computational Simulation**	Employ computational tools and techniques to simulate and validate theoretical models and predictions in physics.
PO4	**Proficiency in Experimental Design and Data Analysis**	Design and execute experiments, interpret data, and analyze results to address scientific questions and solve problems.
PO5	**Contribution to Societal Advancement**	Investigate scientific problems and propose solutions that offer significant benefits to society and address societal needs.
PO6	**Competency in Modern Scientific Tools**	Utilize contemporary tools and technologies effectively for scientific research, design, and analysis.
PO7	**Design for Real-World Constraints**	Develop systems, components, or processes that meet specific needs while addressing constraints such as environmental impact, safety, and sustainability.
PO8	**Adherence to Ethical Standards**	Understand and apply ethical principles and practices in scientific research and professional conduct.
PO9	**Collaboration in Multidisciplinary Projects**	Work effectively in teams on multidisciplinary projects, contributing to research and industry initiatives.
PO10	**Innovation in Addressing Emerging Challenges**	Address new scientific and societal challenges through innovative research and design solutions.
PO11	**Excellence in Scientific Reporting**	Demonstrate the capability to manage and report on significant research projects, including producing comprehensive scientific reports, and delivering oral and poster presentations.
PO12	**Advanced Communication Skills**	Develop and exhibit effective communication skills to articulate complex scientific concepts to both specialized and general audiences.

CORE COURSES
(THEORY AND LAB)

Paper Name: **MATHEMATICAL METHODS**

Paper Code: **PHY21401**
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 Outcomes

1. **CO1: Recall and define** key mathematical concepts, such as linear vector spaces, matrices, tensors, complex variables, and differential equations, fundamental to understanding advanced physics problems.

2. **CO2: Explain and interpret** the principles of mathematical physics, including orthogonality, eigenvalues, integral transforms, and group theory, to describe physical systems.

3. **CO3: Solve** complex problems in physics using mathematical techniques, such as Frobenius methods, Sturm-Liouville theory, and Green's functions, demonstrating practical application of theoretical concepts.

4. **CO4: Analyze** physical and mathematical models using tools like special functions, tensors, and group representations, to identify patterns, relationships, and implications.

5. **CO5: Evaluate** the accuracy and feasibility of solutions to complex physical problems using mathematical methods, such as integral transforms and Green's functions, ensuring consistency with theoretical and experimental results.

6. **CO6: Develop** innovative approaches and solutions to interdisciplinary problems by integrating mathematical techniques, such as group theory, symmetry operations, and tensor analysis, into novel applications.

Catalogue 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 Content:

[10 lecture hours]

Module 1: Linear Vector space and Matrices and Tensor

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

[10 lecture hours]

Module 2: Complex variables

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.

[8 lecture hours]

Module 3: Theory of Second Order Linear Homogeneous Differential Equations

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.

[10 lecture hours]

Module 4: Special functions

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.

[5 lecture hours]

Module 5: Inhomogeneous differential equations

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

[8 lecture hours]

Module 6: Integral transforms

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.

[7 lecture hours]

Module 7: Group theory

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: **PHY21402**
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 Outcomes

1. **CO1: Recall and explain** fundamental principles of variational mechanics, Hamiltonian and Lagrangian formulations, and their applications in classical mechanics.

2. **CO2: Interpret and describe** the theoretical framework of canonical transformations, small oscillations, and relativistic mechanics to understand physical systems.

3. **CO3: Apply** the principles of classical mechanics, including Hamilton-Jacobi theory and rigid body dynamics, to solve real-world and theoretical problems.

4. **CO4: Analyze** complex systems, such as small oscillations, rigid body motions, and relativistic collisions, by breaking down their components and identifying conservation laws and symmetries.

5. **CO5: Evaluate** the behavior of mechanical systems, such as tri-atomic molecules and charged particles in electromagnetic fields, using advanced formulations like Poisson brackets and relativistic electrodynamics.

6. **CO6: Design** innovative models and solutions for interdisciplinary challenges using variational principles, chaos theory, and the Lagrangian and Hamiltonian formulations for continuous systems.

Catalogue 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 Content

[5 lecture hours]

Variational Principle and Lagrange’s Equations

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.

[6 lecture hours]

The Hamilton Equations of motion

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.

[6 lecture hours]

Canonical Transformations

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.

[4 lecture hours]

Hamilton-Jacobi Theory Action-Angle Variables

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

[10 lecture hours]

Rigid Body Motion

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.

[4 lecture hours]

Small Oscillations

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.

[10 lecture hours]

Classical mechanics of Special Theory of Relativity

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.

Relativistic Electrodynamics: Equation of motion in an Electromagnetic field, Electromagnetic field tensor, covariance of Maxwell's equations, Maxwell's equations as equations of motion, Lorentz transformation law for the Electromagnetic fields and the fields due to a point charge in uniform motion; Field invariants, Covariance of Lorentz force equation and the equation of motion of a charged particle in an Electromagnetic field.

Special Topics

(*Only 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 I**
Paper Code: **PHY21403**
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 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 the Kronig-Penney model, coherent states, and the Stern-Gerlach experiment, to assess their impact on modern quantum mechanics.

6. **CO6: Create** innovative approaches to solving quantum problems, such as the addition of angular momenta or tests of quantum foundations (e.g., EPR paradox), integrating advanced techniques and interpretations.

Catalogue 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 Content

[6 lecture hours]

Recapitulation of Basic Concepts

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.

[12 lecture hours]

Mathematical Formulation of Quantum Mechanics

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.

[12 lecture hours]

Postulates of Quantum Mechanics

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.

[10 lecture hours]

One Dimensional Problems

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.

[10 lecture hours]

Three Dimensional Problems

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.

[12 lecture hours]

Angular Momentum

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.

Reference Books

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 ApplicationsAuthor: A. *Ghatak*, S. *Lokanathan* Published by Springer Netherlands.

Paper Name: **ELECTRONICS**
Paper Code: **PHY21404**
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

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

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

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

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

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

6. **CO6: Implement** innovative electronic and microprocessor-based systems by integrating analog, digital, and programmable logic components to address interdisciplinary challenges.

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

Active Circuits:

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

Physical Mechanism:

Crystal structures of Electronic materials (Elemental, III- IV and VI semiconductors), Energy Band consideration in solids in relation to semiconductors, Direct and Indirect bands in semiconductor, Electron/Hole concentration and Fermi energy in intrinsic/Extrinsic semiconductor continuity equation, Carrier mobility in semiconductors, Electron and Hole conductivity in semiconductors, Shallow impurities in semiconductors(Ionization Energies), Deep Impurity states in semiconductors, Carrier Trapping and recombination/ generation in semiconductors, Shockley Read theory of recombination, Switching Electronic Devices

Semiconductor 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.

Special Device:

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

Analog Circuits:

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

Minimization Techniques and Logic Gates:

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

Combinational Circuits:

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.

Sequential Circuits:

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

Semiconductor Memory and Programmable Logic:

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

Intel 8085 and 8086 Microprocessor Architecture:

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: **MACHINE LEARNING AND DATA ANALYTICS**

Paper Code: **PHY21460**
Credit: **2**
LTP: **2-0-0**

Course Objective

1. Introduce the evolution of machine learning techniques and the essential components of a machine learning framework, including data preprocessing, feature engineering, and model evaluation.
2. Develop a strong conceptual understanding of supervised and unsupervised learning techniques, such as regression, decision trees, clustering, and support vector machines, and their applications to real-world problems.
3. Explore advanced learning techniques, including Artificial Neural Networks (ANNs) and Convolutional Neural Networks (CNNs), with a focus on their use in image processing and classification tasks.
4. Equip students with the ability to analyze data using statistical techniques such as hypothesis testing, confidence intervals, and outlier detection, ensuring robust data-driven decision-making.
5. Enable students to design and implement end-to-end machine learning models, emphasizing performance analysis, cross-validation, and optimization to address practical challenges in diverse fields.
6. Encourage the integration of theoretical knowledge with hands-on implementation to prepare students for further research, industry roles, or advanced studies in data science and machine learning.

Course Outcomes (CO)

1. **CO1: Recall** the foundational concepts of machine learning, including its evolution, components of the framework, and statistical principles used in data analysis.

2. **CO2: Explain** supervised and unsupervised learning techniques, including regression models, decision trees, clustering methods, and support vector machines, with an emphasis on their applications.

3. **CO3: Apply** machine learning techniques such as linear regression, clustering, and decision trees to real-world datasets, and evaluate their performance using cross-validation and learning curves.

4. **CO4: Analyze** the advantages and limitations of advanced machine learning techniques such as Artificial Neural Networks and Convolutional Neural Networks for image and data classification tasks.

5. **CO5: Evaluate** the reliability and robustness of machine learning models using statistical hypothesis testing, confidence intervals, and goodness-of-fit measures.

6. **CO6: Design and implement** a complete machine learning pipeline, including data preprocessing, model selection, training, testing, and performance analysis, for solving complex problems in data science.

Catalogue Description:

This is a curated course consisting of the fundamental basis of machine learning and covers a wide array of basic and advanced machine learning techniques. This course is designed to aid students of all domains and would allow them to implement state of the art predictive classifiers and clustering solutions along with inquisitive data analytics techniques to formulate data acquisition protocols, perform analysis and create comprehensive reports.

Course Content

Unit I: Fundamentals of Machine Learning [10L]

Evolution of machine learning techniques. Components of machine learning framework: data preprocessing, feature selection and extraction, training, validation and testing, performance analysis, comparison of learning algorithms, cross-validation, learning curves, overfitting and underfitting, statistical hypothesis testing

Unit II: Supervised and Unsupervised Learning Techniques [7L]

Linear and non-linear regression models, Rule-based learning and decision trees, clustering techniques, support vector machines

Unit III: Advanced Learning Techniques [7L]

Artificial Neural Networks, Convolutional neural networks

Unit IV: Data Analysis Techniques [6L]

Descriptive statistics, probability, confidence intervals, hypothesis testing, goodness of fit, outlier detection

Reference Books:

1. "Machine Learning Algorithms" by G. Bonaccorso
2. "Hands-on Machine Learning with Python" by A. Pajankar, A. Joshi
3. "Machine Learning using Python" by M. Pradhan, U. D. Kumar

4. “Hands-On Data Preprocessing in Python” by R. Jafari
5. “Machine Learning with PyTorch and Scikit-Learn” by S. Raschka, Y. Liu, V. Mirjalili

Paper Name: **PHYSICS LAB I**
Paper Code: **PHY22405**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Equip students with practical skills to conduct experiments that illustrate fundamental principles of physics, including measurements and data collection techniques.
2. Develop students' abilities to analyze experimental results, draw meaningful conclusions, and assess the implications of their findings in the context of theoretical concepts in physics.
3. Enable students to understand the physical mechanisms behind semiconductor behavior and the significance of various semiconductor parameters through hands-on experiments.

Course Outcomes:

1. **CO1: Recall** the principles of quantum mechanics, semiconductor physics, and electromagnetism underlying experimental techniques such as the photoelectric effect, Hall effect, and Millikan's oil drop method.

2. **CO2: Explain** the working principles and methodologies of experiments, such as determining Planck's constant, energy band gap, and e/m of electrons, and their significance in physics.

3. **CO3: Perform** experimental setups to determine fundamental physical constants and material properties, such as Planck's constant, e/m ratio, Hall coefficient, and terminal velocity.

4. **CO4: Analyze** the data obtained from experiments, such as the variation of magnetoresistance or the energy band gap, and interpret the results in the context of theoretical predictions.

5. **CO5: Evaluate** the reliability and accuracy of experimental results, such as verifying Bohr's atomic theory or the inverse square law, and identify potential sources of error.

6. **CO6: Design and propose** modifications or extensions to existing experimental setups, such as optimizing the four-probe method or studying alternative materials for Hall effect experiments.

Catalogue Description:

Physics Lab I is a fundamental experimental area of Physics that deals with the understanding of general physics in post graduate level. It comprises of experiments on photo electric effect, band gag measurement in case of semiconductors, electron charge measurement using Millikan's oil drop method, estimation of e/m of electron by magnetic focusing method, estimation of Hall coefficient of n and p-type semiconductors. It consists of knowledge from all areas of physics like quantum mechanical application, or solid-state physics, or e-m theory. It specially deals with the experimental knowledge from these parts in physics. The course will consist of practical classes and demonstration of theories of relevant experiments. The main focus will be on the development of fundamental concepts of physical properties of materials which could be helpful in future to solve various real-life problems. Apart from regular class on experiments some special classes will be arranged for student presentations.

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: Determine the electron charge by Millikan's Oil drop method and hence determine the terminal velocity of the oil drop.

Experiment 3: Determination of e/m of electrons by magnetic focusing method.

Experiment 4: To determine the energy band gap of Ge crystal by Four Probe Method.

Experiment 5: To determine the Hall coefficient of n-type and p-type semiconductor material.

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.

Paper Name: **PHYSICS LAB II**
Paper Code: **PHY22406**
Credit: **3**
LTP: **0-0-3**

Course Objectives

1. Develop practical skills in the use of laser technology and interferometry for optical measurements.
2. Enhance understanding of optoelectronic devices through hands-on experiments with their characteristics and behaviors.
3. Promote critical thinking by applying theoretical knowledge to experimental verification of optical laws.
4. Foster analytical abilities in interpreting and analyzing data from experiments involving semiconductor devices.

Course Outcomes

1. **CO1: Recall and describe** fundamental optical principles, including diffraction, interference, polarization, and the behavior of optoelectronic devices such as solar cells, LDRs, photodiodes, and optocouplers.

2. **CO2: Explain** the working principles and response characteristics of optoelectronic and semiconductor devices, such as DIAC, TRIAC, and SCR, as well as the numerical aperture and losses in optical fibers.

3. **CO3: Perform** experiments using lasers, optical fibers, and optoelectronic devices to measure physical quantities, such as the refractive index, numerical aperture, and polarization properties of light.

4. **CO4: Analyze** the characteristics of optoelectronic devices, such as solar cells, photodiodes, and LDRs, to interpret their response and operational behavior under varying conditions.

5. **CO5: Evaluate** experimental results, such as I-V characteristics of DIAC, TRIAC, and SCR, and assess the performance of optical and optoelectronic systems for practical applications.

6. **CO6: Design and propose** improved setups or modifications for optical and optoelectronic experiments, including laser-based studies and optical fiber applications, to enhance precision and efficiency.

Catalogue Description

Physics Lab II is a fundamental experimental area of Physics in post graduate level that deals with the understanding of laser and fiber optics in physics. It comprises of experiments on Michelson interferometer, solar-cell, photodiode, opto-coupler, LDR, phototransistor, laser, Optical fiber. It consists of knowledge basically from optics, especially from laser and fiber optics. It specially deals with the experimental knowledge from laser and fiber optics in physics. The course will consist of practical classes and demonstration of theories of relevant experiments. The main focus will be on the development of fundamental concepts of laser and fiber optics which could be helpful in future to solve various real-life problems. Apart from regular class on experiments some special classes will be arranged for student presentations.

Course Content

Experiment 1: Determination of refractive index of a glass plate using Laser source based on Michelson interferometry technique.

Experiment 2: To observe the diffraction pattern and calculate the slit width using Laser light.

Experiment 3: 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 4: To study polarization properties of light and verify the Malu's Law using Laser source.

Experiment 5: 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 6: Studies on I-V characteristics of a DIAC.

Experiment 7: Studies on I-V Characteristics of SCR (Silicon controlled Rectifier).

Experiment 8: Studies on Terminal and Gate characteristics of TRIAC.

Paper Name: **CLASSICAL ELECTRODYNAMICS**
Paper Code: **PHY21407**
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 Outcomes:

1. **CO1: Recall and describe** fundamental principles of electrostatics, magnetostatics, Maxwell's equations, and the dynamics of electromagnetic fields.

2. **CO2: Explain** the derivation and applications of Jefimenko's equations, Larmor's formula, and multipole expansions in understanding time-dependent and static electromagnetic systems.

3. **CO3: Solve** problems related to radiation from moving charges, including Bremsstrahlung, synchrotron radiation, and Cherenkov radiation, using Lienard-Wiechert potentials and relativistic dynamics.

4. **CO4: Analyze** the limitations of classical electrodynamics and the radiation reaction problem, including the Abraham-Lorentz formula and energy conservation issues.

5. **CO5: Evaluate** electromagnetic systems using advanced formulations, such as the energy-momentum tensor, Maxwell's stress tensor, and the conservation laws for relativistic electrodynamics.

6. **CO6: Develop** theoretical models for electromagnetic field dynamics using relativistic Lagrangian and Hamiltonian formulations, and explore extensions into plasma physics.

Catalogue 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 Content:

[12 lecture hours]

Electrostatics and Magnetostatics:

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.

[6 lecture hours]

Maxwell’s Equations in stationary and moving media

Quantitative discussion.

[12 lecture hours]

Fields due to time dependent charge and current distributions

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

[12 lecture hours]

Radiation from moving point charges

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.

[8 lecture hours]

Radiation Reaction

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

[6 lecture hours]

Relativistic Electrodynamics

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 electromagne 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: **QUANTUM MECHANICS II**
Paper Code: **PHY21408**
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.

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.

6. **CO6: Develop** theoretical models using advanced quantum mechanical frameworks, such as relativistic formulations and the Wigner-Eckart theorem, to address complex physical systems and predict outcomes.

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 Content

[18 lecture hours]

Approximation methods in quantum mechanics

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.

[10 lecture hours]

Time dependent perturbation theory

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.

[10 lecture hours]

Scattering Theory

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.

[6 lecture hours]

Symmetries in quantum mechanics

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.

[4 lecture hours]

Identical Particles

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

[10 lecture hours]

Relativistic Quantum Mechanics

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: **STATISTICAL MECHANICS**
Paper Code: **PHY21409**
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.

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.

6. **CO6: Implement** theoretical models for phase transitions, renormalization group analysis, and mean-field approximations, and explore extensions into non-equilibrium statistical mechanics.

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 Content:

[5 lecture hours]

Basic Introduction

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.

[15 lecture hours]

Classical Statistical Mechanics

(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.

[8 lecture hours]

Statistical Mechanics for Interacting Systems:

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

[15 lecture hours]

Quantum statistical mechanics

(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*.

[10 lecture hours]

Phase Transition and Mean Field Theory

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.

[5 lecture hours]

Non-equilibrium Statistical Mechanics

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: **PHY21410**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To provide an in-depth understanding of atomic and molecular spectroscopy, focusing on the theoretical foundations and experimental techniques.
2. To explore the interaction of atoms and molecules with electromagnetic radiation, external fields, and the resulting spectral phenomena.
3. To introduce the principles and applications of various types of spectroscopy, including microwave, infrared, Raman, and spin resonance spectroscopy.
4. To apply group theory to analyze the symmetry properties of molecules and predict spectroscopic behavior.

Course Outcomes:

1. **CO1: Recall and describe** the fundamental principles of atomic and molecular spectroscopy, including one-electron and many-electron atoms, interaction with radiation, and the Stark and Zeeman effects.

2. **CO2: Explain** the theoretical frameworks, such as the Dirac equation, Hartree-Fock method, Born-Oppenheimer approximation, and group theory, and their applications in spectroscopy.

3. **CO3: Apply** principles of rotational, vibrational, Raman, and spin resonance spectroscopy to analyze the structure and dynamics of atoms and molecules.

4. **CO4: Analyze** atomic and molecular systems under external fields and perturbations, such as Stark and Zeeman effects, to determine spectral properties and energy shifts.

5. **CO5: Evaluate** molecular symmetries and transitions using group theory, character tables, and selection rules to predict vibrational modes and electronic structures.

6. **CO6: Design** theoretical models and computational approaches for the interpretation of complex spectroscopic data, including NMR, ESR, and Mossbauer spectroscopy.

Catalogue Description

Atomic and Molecular Spectroscopy gives a fundamental knowledge about the interaction of atomic and molecular systems with the electromagnetic fields. It is all about the techniques to invade inside the atomic domain.

Course Content

Atomic Spectroscopy

[12 lecture hours]

Review of One-Electron Atom:

Review of one electron atom, Dirac equation, Dirac equation in non-relativistic limit i.e., Paoli equation, Fine structure of Hydrogen atom (relativistic correction, coupling due to Spin-Orbit coupling, Derwin term), Lamb shift, Hyperfine structure and isotope shifts.

[8 lecture hours]

Interaction of atoms with electromagnetic radiation:

Classical treatment of the incident radiation, Quantization of the electro-magnetic field, transition rates for emission and absorption of radiation, dipole approximation, Einstein coefficients, selection rules, Spontaneous Emission.

[6 lecture hours]

Interaction with external electric and magnetic field:

Stark effect, Zeeman effect (weak field and strong field limits).

[6 lecture hours]

Two electron atoms:

Schrodinger equations, para and ortho states, Pauli's exclusion principle, ground state and excited state

[5 lecture hours]

Many electron atoms:

Central field approximation, Thomas- Fermi model, Hartree-Fock method, Exchange degeneracy, Symmetrization postulate, Constructing symmetric and anti-symmetric functions, Pauli's Exclusion principle, L-S and J-J coupling, Hund's Rule.

Molecular Spectroscopy

[6 lecture hours]

General Concept

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.

[6 lecture hours]

Microwave spectroscopy

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

[5 lecture hours]

Infrared spectroscopy

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

[4 lecture hours]

Raman spectroscopy

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

[4 lecture hours]

Spin resonance spectroscopy

NMR spectroscopy for hydrogen and other nuclei, ESR spectroscopy.

[4 lecture hours]

Mossbauer spectroscopy

Principle and applications.

[2 lecture hours]

Group Theory in Spectroscopy

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

Reference Books

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: **MACHINE LEARNING AND DATA ANALYTICS LAB**
Paper Code: **PHY22461**
Credit: **2**
LTP: **0-0-2**

Course Objectives:

1. Introduce students to the basics of Pandas and Scikit-learn for data handling and analysis.
2. Teach students to perform data visualization and preprocessing techniques such as scaling, normalization, and feature engineering.
3. Familiarize students with regression models, both linear and nonlinear, and help them implement these models in Python.
4. Explore clustering techniques like K-means and hierarchical clustering to allow students to apply them to real-world datasets.
5. Provide a foundation in decision tree models and their implementation using Python.
6. Introduce students to neural networks, focusing on the basics of PyTorch and perceptron models.

Course Outcomes:

1. **CO1: Recall** the fundamental concepts of data manipulation using Pandas, data visualization in Jupyter Notebook, and machine learning basics using Scikit-Learn.
2. **CO2: Explain** the concepts of feature selection, data scaling, normalization, and dimensionality reduction techniques, such as Principal Component Analysis (PCA).
3. **CO3: Apply** machine learning techniques, such as regression (linear, logistic), K-Nearest Neighbors, and clustering (K-Means, agglomerative), to solve data-driven problems using Python.
4. **CO4: Analyze** the performance of clustering methods, such as hierarchical strategies and dendrograms, and interpret decision tree outputs for classification tasks.
5. **CO5: Evaluate** the performance of models using decision trees, neural networks, and PyTorch frameworks by assessing their accuracy, interpretability, and computational efficiency.
6. **CO6: Design and implement** machine learning pipelines, integrating feature engineering, regression, clustering, and neural networks to address real-world challenges.

Catalogue Description:

This course provides hands-on experience in machine learning and data analytics through a series of practical lab exercises. Students will gain proficiency in popular Python libraries such as Pandas and Scikit-Learn, and explore key concepts in data preprocessing, feature engineering, regression, clustering, decision trees, and neural networks.

Course Content

Unit I: Introduction to Pandas and Scikit-Learn

Basic Concept of Pandas, Pandas Dataframes, Visualization the Data in Dataframes, Idea of Jupyter Notebook, Overview of Scikit-Learner

Unit II: Feature Selection and Feature Engineering

Data Scaling and Normalization, Feature Selection and Filtering, Principal Component Analysis

Unit III: Fundamentals of Regression

Linear and Nonlinear Models, Logistic Regression, K-Nearest Neighbours

Unit IV: Fundamentals of Clustering

K-Means, Agglomerative Clustering, Hierarchical Strategies, Dendrograms

Unit V: Fundamentals of Decision Trees

Building Decision Tree, Binary Decision Trees, Decision Tree in Python

Unit VI: Fundamentals of Neural Networks

Basics of PyTorch, Perceptron, Introduction to Artificial Neural Networks

Reference Books:

1. "Machine Learning Algorithms" by G. Bonaccorso
2. "Hands-on Machine Learning with Python" by A. Pajankar, A. Joshi
3. "Machine Learning using Python" by M. Pradhan, U. D. Kumar
4. "Hands-On Data Preprocessing in Python" by R. Jafari
5. "Machine Learning with PyTorch and Scikit-Learn" by S. Raschka, Y. Liu, V. Mirjalili

Paper Name: **PHYSICS LAB III**
Paper Code: **PHY22411**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Teach students to analyze and study the current-voltage characteristics of a CdS photoresistor.
2. Enable students to measure the temperature dependence of Hall coefficients in semiconductor materials.
3. Guide students in determining the magnetic properties of ferromagnetic substances using hysteresis loop tracers.
4. Provide hands-on experience with interferometry, spectroscopy, and temperature transducers for advanced physical measurements.

Course Outcomes:

1. **CO1: Recall and describe** the fundamental principles of semiconductors, magnetism, temperature transducers, spectroscopy, and optical systems used in experimental setups.

2. **CO2: Explain** the physical principles underlying experiments such as the Hall effect, hysteresis loop, Zeeman effect, and electron spin resonance spectroscopy.

3. **CO3: Perform** experiments to measure physical parameters, such as Hall coefficient, magnetic hysteresis, wavelength of light, and vibrational spectra, using appropriate setups.

4. **CO4: Analyze** experimental data, such as the intensity dependence of CdS photoresistor, temperature dependence of Hall coefficient, and vibrational coarse structure of I_2, to interpret underlying physical phenomena.

5. **CO5: Evaluate** the accuracy and reliability of experimental results, such as Lande-g factor determination, Zeeman effect measurements, and temperature transducer characteristics, by assessing potential sources of error.

6. **CO6: Propose** improvements or modifications to experimental setups, such as optical systems and sensor measurements, to enhance precision and address new research questions.

Catalogue Description:

This course aims to impart knowledge of physical properties of semiconductor materials, magnetic materials and sensors materials. Students will study magneto-resistance and temperature dependence hall coefficients of *n-type* and *p-type* semiconductor material. In addition, they will perform the characterization of ferromagnetic materials substance by using *Hysteresis Loop Tracer* *setup*. Students can able to characterize the properties of various temperature sensors like; Thermocouple Sensors, IC Sensor, etc,. The course consists of practical classes and demonstration of theories of relevant experiments. We mainly focus on the development of fundamental concepts which could be helpful in future to solve various practical problems. Apart from regular class on experiments some special classes will be arranged for student presentations.

Course Content:

Experiment 1: Study of Current Voltage characteristic of a *CdS*, a photo resistor as a function of Intensity using optical bench.

Experiment 2: Determine temperature dependence of Hall coefficient of n-type and p-type semiconductor material.

Experiment 3: Determination of magnetic parameters (Coercive field, residual magnetization and saturation of magnetization) of a Ferromagnetic substance by using *Hysteresis Loop Tracer setup*

Experiment 4: Study of characteristics of *Temperature Transducer*. (Thermocouple Sensors, IC Sensors)

Experiment 5: Determination of Lande-g factor by using Electron Spin Resonance Spectroscopy.

Experiment 6: Determination of wavelength of a monochromatic source by using Michelson’s

Experiment 7: *Study of Zeeman Effect.*

Experiment 8: *Study of Vibrational Coarse Structure of I_2 molecule.*

Paper Name: **NUMERICAL MODELING FOR PHYSICISTS AND ENGINEERS**
Paper Code: **PHY22413**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Introduce students to the basics of programming in Python/Mathematica/Matlab/Scilab for numerical problem-solving.
2. Equip students with methods to solve algebraic, transcendental, and differential equations using computational techniques.
3. Provide experience in applying numerical methods to real-world physics problems like harmonic oscillators and electric circuits.
4. Foster problem-solving skills through the application of matrix operations, interpolation, and numerical integration techniques.

Course Outcomes:

1. **CO1: Recall** the fundamental concepts of numerical methods, such as solving algebraic and differential equations, interpolation, and matrix operations, using programming languages like Python, Mathematica, Matlab, or Scilab.

2. **CO2: Explain** the principles of numerical algorithms, such as Newton-Raphson, Runge-Kutta, and Monte Carlo methods, and their application to physical problems.

3. **CO3: Apply** numerical techniques to solve real-world problems, including eigenvalue problems, electric circuit analysis, coupled mass-spring systems, and differential equations using appropriate programming tools.

4. **CO4: Analyze and interpret** numerical results for physical systems, such as pendulum motion, harmonic oscillators, and Schrödinger equations, using appropriate boundary and initial conditions.

5. **CO5: Evaluate** the accuracy and efficiency of numerical methods by comparing numerical results with analytical solutions for benchmark problems.

6. **CO6: Develop** advanced numerical simulations for solving complex differential equations and optimization problems, integrating visualization techniques for better interpretation.

Catalogue Description

This course aims to impart skill of different Numerical Techniques which are extremely useful in obtaining results of many theoretical problems where getting an analytical solution is impossible.

Course Content

A brief review on any language Python/Mathematica/Matlab/scilab.

Solution of the following numerical problems using Python/Mathematica/Matlab/scilab.

1. Numerical solution of Algebraic and Transcendental equations by Bisection, Newton Raphson and Secant methods, Solution of linear and quadratic equation, solving diffraction equation $\alpha = \tan\alpha$, $I = I_0\left(\frac{\sin\alpha}{\alpha}\right)^2$ in optics.

2. Interpolation by Newton Gregory Forward and Backward difference formula, Error estimation of linear interpolation.

3. Numerical differentiation (Forward and Backward difference formula) and Integration (Trapezoidal and Simpson rules), Monte Carlo method.

4. Solution of Linear system of equations by Gauss elimination method and Gauss Seidal method.

5. Diagonalization of matrices, Inverse of a matrix, Eigen vectors, eigen values problems,

6. Solution of mesh equations of electric circuits (3 meshes), Solution of coupled spring mass systems (3 masses).

7. First order differential equation, Euler, Modified Euler and Runge-Kutta second order method. Solve equations for radioactive decay, Newton's law of cooling , classical equations of motion etc.

8. Second order differential equation solving by RK 4 method, Harmonic oscillator (no friction), Damped Harmonic oscillator, Over damped, Critical damped, Oscillatory, Forced Harmonic oscillator, Transient and Steady state solution.

9. Finite Difference method to solve 2nd order Differential Equation, Solution of Schrodinger Equation in 1D for different given potentials.

To solve some problems on differential equations like:

I. Solve the coupled first order differential equations

$$\frac{dx}{dt} = y + x - \frac{x^3}{3}, \ \frac{dy}{dt} = -x$$

for different initial conditions [e.g., x(0) = 0, y(0) = -1, -2, -3, -4]. Plot x vs. y for each of the four initial conditions on the same screen for $0 \leq t \leq 15$.

II. The ordinary differential equation describing the motion of a pendulum is
$\theta'' = -\sin(\theta)$

The pendulum is released from rest at an angular displacement α i.e. $\theta(0) = \alpha$, $\theta'(0) = 0$. Use the RK4 method to solve the equation for α = 0.1, 0.5 and 1.0 and plot θ as a function of time in the range $0 \leq t \leq 8\pi$. Also, plot the analytic solution valid in the small θ ($\sin\theta \approx \theta$).

III. Solve the differential equation:

$$x^2 \frac{d^2y}{dx^2} - 4x(1+x)\frac{dy}{dx} + 2(1+x)y = x^3$$

with the boundary conditions: at x = 1, $y = (1/2)e^2$, $dy/dx = -(3/2)e^2 - 0.5$, in the range $1 \leq x \leq 3$. Plot y and dy/dx against x in the given range. Both should appear on the same graph.

Paper Name: **SOLID STATE PHYSICS**
Paper Code: **PHY21414**
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.

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.

6. **CO6: Create** theoretical frameworks or conceptual models for exploring advanced topics in solid-state physics, such as dielectric and magnetic properties.

Catalogue Description:

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

Course Content

[12 lecture hours]

Crystal Structure, Electron Diffraction and Lattice vibrations

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

[14 lecture hours]

Free Electron model and Energy bands in solids

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.

[14 lecture hours]

Transport and Dielectric properties of Solids

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

[16 lecture hours]

Magnetism and Superconductivity

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.

<u>Special Topics</u>

(*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:

5. "Introduction to Solid State Physics" by Charles Kittel
6. "Solid State Physics" by Neil W. Ashcroft and N. David Mermin
7. "Solid State Physics: Structure and Properties of Materials" by M.A. Wahab
8. "Magnetism in Condensed Matter" by Stephen Blundell
9. "Introduction to Superconductivity" by Michael Tinkham

Paper Name: **NUCLEAR AND PARTICLE PHYSICS**
Paper Code: **PHY21415**
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.

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.

6. **CO6: Design** qualitative or quantitative approaches to explore advanced topics such as nuclear reactions, neutrino physics, and particle decays in accordance with conservation laws.

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 Content

[8 lecture hours]

Nuclear Properties

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

[12 lecture hours]

Two body Bound State and Scattering State

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.

[6 lecture hours]

Beta Decay:

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.

[8 lecture hours]

Nuclear Structure:
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.

[8 lecture hours]

Nuclear Reaction and Fission:

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.

[14 lecture hours]

Particle Physics and Strong Interactions:

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.

[4 lecture hours]

Neutrino Physics

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

Paper Name: **PHYSICS LAB IV**
Paper Code: **PHY22412**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Design passive and active filters and analyze their frequency responses.
2. Construct various flip-flop circuits and counters using digital ICs.
3. Study modulation techniques in amplitude and frequency, enhancing understanding of communication systems.
4. Develop multivibrator circuits to explore different states and their applications in timing and control.
5. Implement practical electronics projects, fostering hands-on skills and theoretical understanding in electronics.

Course Outcomes:

1. **CO1: Identify** the principles and components required to design and analyze various passive and active filter circuits.

2. **CO2: Explain** the working principles of T-section, π-section filters, and modulation techniques in communication systems.

3. **CO3: Construct and analyze** the operation of flip-flops, counters, and shift registers using ICs and basic logic gates.

4. **CO4: Analyze** the frequency response, timing diagrams, and modulation-demodulation characteristics of circuits to assess their performance.

5. **CO5: Evaluate** the performance of multivibrators and filters for specific applications, comparing design parameters and experimental results.

6. **CO6: Design and optimize** advanced circuits such as multivibrators, filters, and modulators/demodulators using transistors and ICs for real-world applications.

Course Description:

This course aims to impart knowledge of filters in electronic devices and to study of I-V characteristics of different power semiconductor devices *like*: DIAC, SCR, TRIAC etc. Students can able to classify the characteristics of filter circuits and also learn the utilization of power semiconductor devices. The course will consist of practical classes and demonstration of theories of relevant experiments. We mainly focus on the development of fundamental concepts which could be helpful in future to solve various practical problems. Apart from regular class on experiments some special classes will be arranged for student presentations.

Course Content:

Experiment 1:

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.

Experiment 2:

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 3: 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 4: To build a 4-bit Counter using D-type/JK Flip-Flop ICs and study timing diagram.

Experiment 5: To make a 4-bit Shift Register (serial and parallel) using D-type/JK Flip-Flop ICs.

Experiment 6: Study of Amplitude modulation and demodulation.

Experiment 7: Study of Frequency modulation and demodulation.

Experiment 8: Design and study of an Astable, Monostable and Bi-stable multivibrator by using transistor.

Experiment 9: Design and study of an Astable, Monostable and Bi-stable multivibrator by using 555

DISCIPLINE SPECIFIC ADAVNCED ELECTIVE COURSES (THEORY AND LAB)

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

Specialization: ***Condensed Matter Physics***

Paper Name: **MANY BODY THEORY**
Paper Code: **PHY21416**
Credit: **4**
LTP: **4-0-0**

Course Objectives

1. Explain the fundamental principles of many-electron systems and their interactions.
2. Utilize second quantization techniques to analyze many-electron Hamiltonians.
3. Apply the Hartree-Fock method for calculating ground state energies and other properties of interacting electron systems.
4. Investigate the Hubbard Hamiltonian and its relevance to Mott transitions and other phenomena.
5. Demonstrate proficiency in diagrammatic perturbation theory and its application to many-electron systems.
6. Analyze Green's functions and their use in solving the one-electron Schrödinger equation.

Course Outcomes

1. **CO1: Recall** the fundamental principles of many-electron systems, including the Schrödinger equation and perturbation theory.

2. **CO2: Explain** the concepts of second quantization, including creation and annihilation operators, commutation relations, and vacuum state.

3. **CO3: Apply** the Hartree-Fock method to calculate ground-state energy, specific heat, and correlation energies in interacting electron systems.

4. **CO4: Analyze** the behavior of many-electron systems using Hubbard Hamiltonian models, including Mott insulators, t-J models, and magnetic impurities.

5. **CO5: Evaluate** Feynman diagrams in diagrammatic perturbation theory, distinguishing between linked and unlinked graphs, and their implications for many-body systems.

6. **CO6: Develop** Green's function-based approaches to analyze the density of states in systems under perturbation and solve one-electron Schrödinger equations.

Catalogue Description

Many Body Theory is the foundation of correlated electron system, which is a very significant part of Theoretical Condensed Matter Physics. This part deals with many electron systems where the electron-electron interaction is taken into account through mean field approach (commonly known as Hartree-Fock Method, Hartree Method etc.) and diagrammatic perturbation theory.

Course Content

[10 lecture hours]

Fundamentals of many-electron system

Schrodinger equation for a many electron system, Matrix elements of non-interacting and interacting part, applicability of perturbation theory to solve an interacting many electron problem.

[8 lecture hours]

Second Quantization

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.

[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.

[8 lecture hours]

Hubbard Hamiltonian

Mott transition, Introduction to Hubbard model, extended Hubbard model, Mott insulators, t-J model, magnetic impurities, Kondo effect and related problems

[12 lecture hours]

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

[10 lecture hours]

Green's Function and one-electron Schrodinger equation

Green's function operator, Density of states of a system subjected to small perturbation

Reference Books:

1. S. Raimes: Many Electron Theory
2. Many Body Theory in Condensed Matter Physics, Henric Bruus and Karsten Flensberg
3. A Guide to Feynman Diagrams in the Many-body Problem, R. D. Mattuk
4. The Green Function Method in Statistical Mechanics, V. L. Bonch-Bruevich
5. Many Particle Physics, Gerald D. Mahan, Springer US.

Paper Name: **MATERIAL SCIENCE**
Paper Code: **PHY21421**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Introduce fundamental concepts of material science, including structure, bonding, and properties of various materials.
2. Develop an understanding of symmetry in crystalline structures and its impact on material properties.
3. Analyze defects in crystalline materials and their effects on mechanical properties and performance.
4. Explore the electronic properties of materials, focusing on band structure and semiconductor devices.
5. Familiarize students with synthesis and characterization techniques for advanced materials.

Course Outcomes:

1. **CO1: Recall** the structure, bonding, and classification of various materials, including crystalline and amorphous solids, ceramics, polymers, graphene, and carbon nanotubes.

2. **CO2: Explain** the concepts of symmetry in crystalline structures, including Bravais lattices, symmetry operations, and crystal field splitting, along with the idea of quasicrystals.

3. **CO3: Apply** the principles of crystallographic defects, band structure, and transport properties to analyze material behavior under various conditions such as temperature and pressure.

4. **CO4: Analyze** the properties of advanced materials such as multiferroic materials, piezoelectrics, and magnetoresistive materials using theoretical models like the Landau-Ginzburg theory and Boltzmann transport equation.

5. **CO5: Evaluate** phase transitions and synthesis techniques, including critical phenomena, single crystal growth, and nanomaterial fabrication, to determine their practical and technological relevance.

6. **CO6: Design** experiments and utilize characterization techniques like XRD, SEM, TEM, and nuclear techniques to synthesize and analyze advanced materials and alloys.

Catalogue Description:

This course aims to impart knowledge about principles and applications of material science. Students will be able to know various properties of materials. The course is designed in such a way students can get a complete idea about crystal structure, defects associated with the crystalline structure. Like many other things, materials are classified into different groups. One can classify them based on many criteria; for example crystal structure (arrangement of atoms and bonds between them) or properties or use of materials. Metals, Ceramics, Polymers, Composites, Semiconductors, and Biomaterials, are the main classes of materials. In this course students will learn about the properties of materials also. The course will consist of lectures and tutorial classes. We mainly focus on the development of fundamental concepts which can be addressed further to solve various real life problems where concepts of material science are required. Regular class tests will be taken and some special classes will be arranged for student presentation and for student-teacher interaction.

Course Content:

[6 lecture hours]

Overview of Materials
Structure and bonding in solids, crystalline solids: (metals/insulator/semiconductor). Amorphous materials: Glasses and their application, Oxide and nitride semiconductors, solar energy materials, luminescent and optoelectronic materials, Structure and properties of ceramics and polymers. Graphene and Carbon Nano Tube (Density of States, Elementary electronic properties and band structure), Single wall and multiwall carbon nanotube, Carbon nano-tubule based electronic devices.

[12 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.

[10 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 colour centres 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.

[15 lecture hours]

Properties of Materials

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 absorbtion in semiconductor, Semiconductor junction and devices p-n junction, Junction rectifier, The junction transistor, Tunnel diode, Photodiode.

Transport and Magnetic Property: The Boltzmann transport equation. Classifications of electrical properties: Resistivity variation of metals at low and high temperature, temperature variation of dc conductivity, ac conductivity and magneto-resistance, Effect of pressure on resistivity, resistivity variation in ceramics and conducting polymer, Thermoelectric effects, Thermal conductivity. Ferroelectricity, Landau Ginzburg theory of ferroelectricity, Piezoelectricity, A brief discussion on Multiferroic materials.

Energy levelsand density of states in a magnetic field; Landau diamagnetism; de Haas-van Alphen effect, Hall Effect and magneto-resistance, Cyclotron resonance, Azbel-Kaner resonance, Colossal magneto-resistance (CMR).Giant magneto-resistance (GMR):basic properties, mechanism, Application: spin valves and spin switches. Theoretical understanding: Double exchangemechanism, crystal field splitting and *Jahn-Teller* distortion, electron phonon coupling.

[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.

[6 lecture hours]

Synthesis and Characterization of materials

- Single crystal growth, zone refining, Fabrication process of thin films: thermal evaporation/PLD/CVD. Nano-materials: synthesis, properties and applications, Alloys: synthesis and study of Half and Full Heusler alloys, shape memory effects in alloys.

- Structure: X-ray diffraction (XRD) patterns, Identification of phases, effects of disorder, Strain and crystallite size. Morphology: Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Study of selected area diffraction patterns, Nuclear techniques: NMR, ESR, and Characterization of defects by Positron annihilation lifetime spectroscopy.

Reference Books

1. C. Kittel: Introduction to Solid State Physics
2. R. Zallen: The Physics of Amorphous Solids.
3. N.W. Ashcroft and N.D. Mermin: Solid State Physics
4. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiment
5. J. P. Srivastava: Elements of Solid State Physics

6. S. Blundell : Magnetism in Condensed Matter, OXFORD University Press
7. N.F. Mott and E.A. Davies: Electronic Processes in Non-crystalline Materials
8. Quantum Theory of Solids, C. Kittel
9. J. Dekker: Solid State Physics

Paper Name: **COLLECTIVE PHENOMENA OF SOLIDS**
Paper Code: **PHY21432**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Equip students with advanced theoretical knowledge of magnetism and superconductivity.
2. Develop analytical skills to evaluate complex physical phenomena related to magnetic and superconducting materials.
3. Foster practical skills in designing experiments and analyzing data relevant to magnetism and superconductivity.
4. Enhance students' understanding of the societal implications of advancements in magnetic and superconducting technologies.
5. Cultivate proficiency in utilizing modern scientific tools and techniques for experimental and computational physics.

Course Outcomes:

1. **CO1: Define** fundamental concepts of magnetism and superconductivity, including dipole interactions, exchange interactions, and Cooper pairing.

2. **CO2: Explain** advanced magnetic phenomena like spin waves, Jahn-Teller effects, and superconducting properties, including Meissner effects and energy gap temperature dependence.

3. **CO3: Apply** theoretical models such as the Ising model, t-J model, and BCS Hamiltonian to analyze magnetic and superconducting materials.

4. **CO4: Analyze** experimental techniques like SQUID, VSM, tunneling spectroscopy, and neutron scattering to characterize magnetic and superconducting materials.

5. **CO5: Evaluate** practical applications of magnetism and superconductivity, such as in MRI, particle accelerators, superconducting electronics, and quantum computing.

6. **CO6: Develop** innovative approaches to study advanced topics, such as high-temperature superconductors, spintronics, and room-temperature superconductors, by integrating experimental and theoretical insights.

Catalogue Description

Collective phenomena of solids are a branch of advanced Condensed Matter Physics which deals with the phenomenological properties and underlying mechanism of Magnetism and superconductivity of solids. We also illustrate the theoretical formalism of topological insulators and superconductors.

Course Content:

[24 lecture hours]

Magnetism:

Magnetism- the phenomenon, Bohr-van Leeuwen theorem, dipole-dipole interaction. Magnetism of free atoms and ions, Magnetic ions in crystals, Transition metal ions, Jahn-Teller effect, Origin of the exchange interaction, Direct exchange, Super exchange, Indirect exchange and itinerant exchange, Mean Field Theory for magnetic insulators, Spin-waves in ferromagnets, magnons, Bloch Spin wave theory, Holstein-Primakoff transformation, Heisenberg Ferromagnet, Heisenberg anti-ferromagnet, Spontaneous magnetization, thermodynamics of magnons, Spin-waves in lattices with a basis, ferri- and Antiferromagnetism, Measurement of magnon spectrum, Ordered magnetism of valence and conduction electrons, Stoner's criterion for metallic ferromagnet, The Ising Model, Zero external magnetic field (Spontaneous Symmetry breaking), t-J model, Nagaoka ferromagnetism, Experimental Techniques in Magnetism- Magnetometry: SQUID, VSM, and Hall effect measurements, Neutron and X-ray scattering in magnetic materials, Magnetic imaging techniques: MFM and Lorentz microscopy.

[30 lecture hours]

Superconductivity:

Superconductors, Cooper pairing, Qualitative analysis of BCS Hamiltonian, BCS wave-functions, BCS Hamiltonian, Estimation of ground state energy, Diagonalization of BCS Hamiltonian, Bogoliubov Transformation, Estimation of Energy Gap, Temperature dependence of energy gap, London equation, Meissner effect, Type-II superconductors characteristic length, Josephson effect, Novel High Temperature superconductors, Josephson Junctions. Andreev reflection, basic understanding in continuum, applications of Andreev Reflection spectroscopy.
Experimental Techniques in Superconductivity- Electrical and magnetic measurements: Four-point probe and AC susceptibility. Josephson effect and superconducting quantum interference devices (SQUIDs), Tunneling spectroscopy and scanning tunneling microscopy (STM). Applications of Superconductivity- Superconducting magnets: MRI and particle accelerators, Superconducting electronics: Quantum computing and microwave devices, Future directions: Room-temperature superconductors and superconducting spintronics.

References Books:

1. "Introduction to Solid State Physics" by Charles Kittel
2. "Principles of Condensed Matter Physics" by P. M. Chaikin and T. C. Lubensky

3. "Magnetism in Condensed Matter" by Stephen Blundell
4. "Superconductivity: A Very Short Introduction" by Stephen Blundell

Paper Name: **DIELECTRIC OPTICAL AND TRANSPORT PROPERTIES OF SOLIDS**

Paper Code: **PHY21437**

Credit: **4**

LTP: **4-0-0**

Course Objectives:

1. Provide an in-depth understanding of dielectric and optical properties of solids, including theoretical frameworks and experimental techniques.
2. Equip students with knowledge of transport properties and their significance in solid-state physics.
3. Develop analytical skills to interpret complex phenomena related to light-matter interaction and charge transport in materials.
4. Foster proficiency in utilizing advanced experimental techniques for the study of dielectric, optical, and transport properties.
5. Encourage exploration of contemporary topics such as nonlinear optical properties, photonic crystals, and topological phases of matter.

Course Outcomes:

1. **CO1: Define** fundamental concepts of dielectric and optical properties, including dielectric function, polarizability, optical constants, and interactions of light with matter.

2. **CO2: Explain** advanced concepts like ferroelectric transitions, polarons, plasmons, and mesoscopic transport properties, including electron-phonon interactions.

3. **CO3: Apply** theoretical models such as the Drude model, Boltzmann transport equation, and Landauer-Buttiker formulation to study electrical, thermal, and spin transport phenomena.

4. **CO4: Analyze** experimental techniques such as dielectric spectroscopy, Raman spectroscopy, Hall effect, and thermal transport measurements to characterize material properties.

5. **CO5: Evaluate** the impact of dielectric, optical, and transport properties on technological applications like optoelectronics, photonics, and thermoelectric materials.

6. **CO6: Implement** innovative approaches to study advanced topics such as topological insulators, Dirac semimetals, photonic crystals, and nonlinear optical materials for emerging technologies.

Catalog Description

‘Collective phenomena of solids’ are a branch of advanced Condensed Matter Physics which deals with the phenomenological properties and underlying mechanism of Magnetism and superconductivity of solids. We also illustrate the theoretical formalism of Density Functional Theory which is an extremely powerful tool to calculate the electronic band structure of solids.

Course Content

[30 lecture hours]

Dielectric and Optical properties of solids:

The dielectric function, different polarizability the dielectric function for a harmonic oscillator, dielectric losses of electrons, Kramer’s-Kronig relations, Interaction of Ionic Lattice with Electromagnetic radiation, complex dielectric constant, Longitudinal and transverse polarization, Lyddane-Sachs-Teller relation, Interaction of light with matter: Reflection, refraction, and absorption, Optical constants: Refractive index, extinction coefficient, Electronic band structure and optical transitions. Perovskite crystal structure, Soft modes, different IR active/inactive soft modes in ferroelectric substance, Dielectric energy loss, Absorption of e m radiation through optically thick and thin medium, polaron, polariton, Plasmon, plasma oscillation, Wood Zener Effect, Interband and intraband transition, Ferroelectric phase transion, 1^{st} order and higher order transition.

Experimental Techniques for Dielectric and Optical Studies- Dielectric spectroscopy and impedance analysis, Ellipsometry and reflectometry, Photoluminescence and Raman spectroscopy.

Advanced Topics in Dielectric and Optical Properties- Nonlinear optical properties and materials, Photonic crystals and metamaterials. Applications in optoelectronics and photonics: LEDs, lasers, and solar cells.

[30 lecture hours]

Transport properties

Fundamentals of Transport Properties, Drude model and Boltzmann transport equation, Electrical conductivity and resistivity, Thermoelectric effects: Seebeck, Peltier, and Thomson effects. Phonon transport and thermal conductivity, Electron-phonon interaction and scattering mechanisms. Experimental Techniques for Transport Studies, Electrical transport measurements: Four-point probe, Thermal transport measurements: Laser flash analysis, Magnetotransport measurements: Hall effect, magneto-resistance.

Introduction to mesoscopic systems, idea of length scales, Characteristic features of low-dimensional systems: Conduction quantization, Conduction fluctuation, persistent current etc. Theoretical formulation to study electron and spin transport phenomena: Landauer-Buttiker formulation, Two terminal conductance and current calculation, Landauer Formula, 2D Electron gas and its Density of States, Landau band formation and Quantum Hall effect, Spin Hall Effect (Qualitative discussions only).

Topological phases of Matter, TI and Dirac semimetals, Winding number and Zak phase

Reference Books

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

Paper Name: **MATERIAL SCIENCE LAB**
Paper Code: **PHY22427**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Provide hands-on experience in synthesizing metal thin films using thermal evaporation techniques.
2. Equip students with the skills to analyze the crystalline structure of materials using X-ray diffraction.
3. Develop an understanding of the electrical characteristics of solar cells through practical experimentation.
4. Facilitate the measurement of dielectric properties of ferroelectric materials and determine their phase transition temperatures.
5. Introduce students to nuclear magnetic resonance spectroscopy for determining nuclear properties.
6. Enhance students' practical knowledge of photoresistor characteristics and their dependence on wavelength.

Course Outcomes:

1. **CO1: Recall** the fundamental principles and techniques involved in the synthesis, characterization, and study of materials like metal thin films and ferroelectric materials.

2. **CO2: Explain** the working principles of experimental methods such as thermal evaporation, X-ray diffraction, dielectric measurements, and NMR spectroscopy.

3. **CO3: Perform** experiments to synthesize thin films, analyze I-V characteristics of solar cells, and measure dielectric properties of ferroelectric materials.

4. **CO4: Analyze** experimental data to determine material properties such as Curie temperature, nuclear g factor, and wavelength dependence of photoconductivity.

5. **CO5: Evaluate** the effectiveness and reliability of experimental setups and methods in extracting key physical parameters of materials.

6. **CO6: Design** optimized experimental approaches to study advanced material properties, including photovoltaic and ferroelectric materials, for practical and technological applications.

Catalogue Description:

This course aims to impart knowledge of material science by measuring properties of materials experimentally. The course is designed in a way that students could have got more or less complete idea to determine crystal structure of metallic films, can able to calculate grain size of a material and lattice constants of material. In this course students will perform current voltage characteristic of solar cell, experimentally observe phase transition (Ferro-electric to para-electric) as a function of temperature of $BaTiO_3$ceramics. Students can able to classify materials like: metals, ceramics, and semiconductors by studding their physical properties. The course will consist of practical classes and demonstration of theories of relevant experiments. We mainly focus on the development of fundamental concepts of physical properties of materials which could be helpful in future to solve various real life problems associated with Material Science.

Course Content:

Experiment 1: 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 2: To study I-V characteristic of Solar Cell and determine maximum power output from the I-V curve.

Experiment 3: 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 4: To determine nuclear g factor by using Nuclear Magnetic Resonance Spectroscopy.

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

Paper Name: **CONDENSED MATTER PHYSICS LAB**
Paper Code: **PHY22442**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. To introduce students to the synthesis and characterization techniques for metal thin films.
2. To enable students to understand and measure dielectric properties of materials.
3. To guide students in investigating thermal and magnetic properties of solids.
4. To familiarize students with advanced experimental techniques for optical and transport studies.

Course Outcomes:

1. **CO1: Recall** fundamental principles of magnetism, dielectric materials, and heat capacity relevant to the experiments, such as Quinck's method and Curie temperature.

2. **CO2: Explain** the working principles of experimental methods like dielectric constant measurement, thermal evaporation, XRD, and SEM for material synthesis and characterization.

3. **CO3: Perform** experiments to measure magnetic susceptibility, dielectric constants, Curie temperature, and heat capacity of solids.

4. **CO4: Analyze** experimental data to investigate phase transitions, dispersion relations, and structural properties of synthesized materials.

5. **CO5: Evaluate** the reliability of experimental setups and techniques in extracting structural, thermal, and magnetic properties of bulk and nanoscale materials.

6. **CO6: Design** advanced experimental setups and synthesize materials for structural and morphological studies, integrating concepts of nanotechnology and solid-state physics.

Catalogue Description:

This course aims to impart knowledge of physical properties of materials. Students will study phase transition (*ferromagnetic to paramagnetic*) as a function of temperature of a solid and also understand how response functions (susceptibility, heat capacities) behaves as a function of temperature of solids during phase transitions. In addition, students will study synthesis and structural characterization of metal thin films. By analysing the XRD data they will perform calculation of structural parameters. Based on physical property measurements they can able to classify materials as metals, ceramics, polymers, composites, semiconductors. The course consists of practical classes and demonstration of theories of relevant experiments. We mainly focus on the development of fundamental concepts which could be helpful in future to solve various practical problems.

Course Content:

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

Experiment 2: Measurements of Dielectric constant of a specimen (liquid) at high frequency.

Experiment 3: Determination of Curie temperature of Monel metal.

Experiment 4: Determination of Heat Capacities of Solids.

Experiment 5: Dispersion Relation in periodic electrical circuit, Study of electrical analogue mono-atomic and di-atomic chain.

Experiment 6: Study of Ferromagnetic-Paramagnetic phase transition in Ferrites.

Experiment 7: Synthesis of metal thin films of (Cu/Ag metal) on a glass substrate by using thermal evaporation technique and structural characterization through XRD.

Experiment 8: Synthesis of bulk/ nano-structured Oxide materials (ZnO/ SnO_2) and structural characterization through XRD and morphological study through SEM.

Specialization: ***High Energy Physics***

Paper Name: **QUANTUM FIELD THEORY I**
Paper Code: **PHY21418**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce students to the fundamental principles of field theory and its mathematical framework.
2. To teach students the techniques of canonical quantization for different types of fields.
3. To explore invariance principles and their significance in quantum field theory.
4. To enable students to understand the concepts of interacting fields and perturbation theory.

Course Outcomes:

1. **CO1: Recall** the fundamental principles of quantum field theory, including action principles, Euler-Lagrange equations, and Noether's theorem.

2. **CO2: Explain** the concepts of canonical quantization, propagators, and gauge invariance for scalar, spinor, and electromagnetic fields.

3. **CO3: Apply** theoretical principles to compute Green's functions, Feynman propagators, and use Feynman rules for free and interacting fields.

4. **CO4: Analyze** the invariance principles in field theories, including Lorentz invariance, CPT transformations, and their implications in spin statistics theorems.

5. **CO5: Evaluate** interaction theories using covariant perturbation theory, S-matrix formulations, and Wick's theorem to derive physical insights.

6. **CO6: Develop** innovative approaches to model quantum interactions, interpret Feynman diagrams, and explore applications in advanced field theories.

Catalogue Description:

Quantum field theory is a framework to study the microscopic world of elementary particles and forces. It is an extension of the subject quantum mechanics and the framework encompasses classical field theory, quantum mechanics and special theory of relativity.

Course Content:

[10 lecture hours]

Preliminaries

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

[20 lecture hours]

Free Field

Canonical quantization of scalar and complex scalar fields, Correlators of free scalar field, Retarded, advanced Green functions, Feynman propagator, Canonical quantization of spinor field, Feynman propagators, Quantization of free electromagnetic field, Gauge invariance, Gauge fixing, Physical state condition, Feynman rules

. **[15 lecture hours]**

Invariance Principles

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

[15 lecture hours]

Interacting fields

Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.

Reference Books:

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

Paper Name: **QUANTUM FIELD THEORY II**
Paper Code: **PHY21434**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Provide a foundational understanding of the path integral approach and its application to quantization in both scalar and spinor fields.
2. Introduce and explore Quantum Electrodynamics (QED) and Quantum Chromodynamics (QCD), focusing on gauge invariance, interaction Hamiltonian, and advanced topics like asymptotic freedom and the Higgs mechanism.
3. Facilitate the understanding of key concepts in loops, divergences, and renormalization within quantum field theory, enabling students to calculate self-energy and understand the regularization process.
4. Offer advanced students an opportunity to explore more specialized topics like ϕ^4 theory, and deeper insights into renormalization in Quantum Electrodynamics (QED).

Course Outcomes:

1. **CO1: Define** the fundamental concepts of path integrals, functional integrals, and generating functionals for scalar and spinor fields.

2. **CO2: Explain** the principles of local gauge invariance in Quantum Electrodynamics (QED) and Quantum Chromodynamics (QCD) and their significance in quantum field theory.

3. **CO3: Apply** the path integral approach to compute Green’s functions, two-point and four-point functions, and to analyze fermionic functional integrals.

4. **CO4: Analyze** advanced concepts such as asymptotic freedom, spontaneous symmetry breaking, and Higgs Mechanism in QCD and electroweak theory.

5. **CO5: Evaluate** loop calculations and divergence structures in quantum field theories using techniques like regularization and renormalization.

6. **CO6: Develop** innovative approaches to quantum field theory problems, such as constructing effective actions in ϕ^4 theory and one-loop renormalization of QED.

Catalogue Description:

Quantum field theory is a framework to study the microscopic world of elementary particles and forces. It is an extension of the subject quantum mechanics and the framework encompasses classical field theory, quantum mechanics and special theory of relativity.

Course Content:

Path integral approach of quantization: Scalar and Spinor fields [15 lecture hours]
Introduction to Path Integrals, Generating functional for scalar fields, Functional integral, Free particle Green's function, Two-point functions, Four-point functions, Grassman variable, Fermionic functional integrals and generating functional.

QED [10 lecture hours]
Local gauge invariance, Interaction Hamiltonian, Lowest order processes in QED, example of actual calculation: electron-electron scattering.

QCD [15 lecture hours]
Basic idea of gauge invariances in non-abelian gauge theories, QCD (introduction), Asymptotic freedom, Spontaneous symmetry breaking, Goldstone theorem, Higgs Mechanism, electroweak interactions, and the Weinberg Salam Glashow model.

Loops and Divergences [8 lecture hours]
Basic idea of regularization and renormalization, Degree of divergence. Calculation of self-energy of scalar in φ^4 theory using cut-off or dimensional regularization

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

Path integral approach: Generating functional for interacting fields: ϕ^4 theory. Effective action for ϕ^4 theory.

Loops and divergence: Renormalisation of Quantum Electrodynamics: One-loop structure of QED.

Reference Books:

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

Paper Name: **PARTICLE PHYSICS I**
Paper Code: **PHY21423**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Introduce students to the fundamental concepts of elementary particles and their classification.
2. Explain the interactions and decay processes of elementary particles, along with associated symmetries and conservation laws.
3. Explore hadron spectroscopy and the mathematical frameworks used in particle physics, including SU(2) and SU(3) representations.
4. Examine the dynamics of relativistic kinematics and its applications in particle decays and deep inelastic scattering.

Course Outcomes:

1. **CO1: Recall** the classification of elementary particles, types of interactions, and key concepts such as quarks, leptons, and mediators.

2. **CO2: Explain** the quark model, SU(2) and SU(3) representations, symmetries, conservation laws, and their significance in particle physics.

3. **CO3: Apply** relativistic kinematics and conservation laws to analyze particle decays and scattering processes.

4. **CO4: Analyze** hadron spectroscopy, multiplet structures, and Young Tableaux to interpret particle properties and exotic hadron states.

5. **CO5: Evaluate** experimental findings in deep inelastic scattering, neutrino oscillation, and neutrino mass detection, linking them to theoretical models.

6. **CO6: Develop** innovative approaches to understanding neutrino oscillations, CP violation, and the relationship between neutrinos and the universe's structure.

Catalogue Description:

Particle physics deals with the study of the fundamental properties of building blocks of matter and their interactions. It is basic physics with lots of application in current day research in physics starting from particle to astrophysics. Course outlines the understanding of Elementary particles, basic conservation laws and hidden quantum numbers like iso-spin, baryon numbers, Lepton numbers, colour quantum numbers etc via SU (2), SU (3) symmetry. Exotic hadrons, CP violation and neutrino oscillations are also included.

Course Content

[25 lecture hours]

Introduction to Elementary Particles:

Particle classification, Type of interaction between the elementary particles, Feynman diagram, mediators, hadrons, basic building blocks of nature quark and leptons, resonance particles, internal quantum numbers and Gellman Nishijima formula. The Eightfold way, Quark model of mesons and baryons. Decay of elementary particles, symmetries and conservation laws, charge conjugation, CP violation in weak interaction, CPT theorem, properties of neutrinos, parity, quark-lepton symmetry.

[16 lecture hours]

Hadron Spectroscopy:

Hadron spectroscopy, Multiplets and quarks. Quark flavours, SU(2) representation fundamental representation of SU(2) doublet, isospin, conjugate and regular representation of SU(2). Representation of SU(3), Exotic hadrons. Young Tableaux.

[6 lecture hours]

Relativistic Dynamics and Particle Decays:

Relativistic Kinematics, Conservation laws, applications to decay of elementary particles.

[8 lecture hours]

Deep Inelastic scattering:

Dynamical structure of hadrons, deep inelastic scattering, structure function, Bijorken scaling, exact scaling and scaling violation, experimental aspects.

[5 lecture hours]

Neutrino Oscillation:

Massive neutrinos, Neutrino oscillation-definition, MSW effect, Oscillation probability, life time. Experiments on neutrino mass detection, Universe and neutrino mass.

Reference Books

1. Introduction to Elementary Particles: David Griffiths

2. An introduction to Quarks and Partons: F.E. Close.
3. Introduction to Gauge Field Theories: M. Chaichian and N.F. Nelipa.

Paper Name: **PARTICLE PHYSICS II**
Paper Code: **PHY21439**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Introduce the principles of invariant Lagrangians and their significance in particle physics, including symmetry concepts.
2. Explain the framework of quantum chromodynamics (QCD) and its role in describing strong interactions.
3. Explore experimental techniques and methodologies for testing the Standard Model of particle physics and its predictions.
4. Discuss the properties and implications of quark-gluon plasma, especially in relation to astrophysics.

Course Outcomes:

1. **CO1: Recall** the classification of elementary particles, types of interactions, and key concepts such as quarks, leptons, and mediators.

2. **CO2: Explain** the quark model, SU(2) and SU(3) representations, symmetries, conservation laws, and their significance in particle physics.

3. **CO3: Apply** relativistic kinematics and conservation laws to analyze particle decays and scattering processes.

4. **CO4: Analyze** hadron spectroscopy, multiplet structures, and Young Tableaux to interpret particle properties and exotic hadron states.

5. **CO5: Evaluate** experimental findings in deep inelastic scattering, neutrino oscillation, and neutrino mass detection, linking them to theoretical models.

6. **CO6: Develop** innovative approaches to understanding neutrino oscillations, CP violation, and the relationship between neutrinos and the universe's structure.

Catalogue Description:

Particle physics deals with the study of the fundamental properties of matter and their interactions. Course includes detailed mathematical formulations of strong interactions via Gauge theories, Symmetry breaking, Lagrangian formalism and Quantum Choromo Dynamics (QCD). QGP states and its interface with early universe are discussed in detail. The course in fact teaches all the areas of particle physics with mathematical techniques, theories and applications including future research prospects.

Course Content

[14 lecture hours]

Invariant Lagrangian:

Invariant Lagrangian, U(1) symmetry, Globally and locally invariant Lagrangian, Gauge fields, Degeneracy of vacuum states and spontaneous breakdown of symmetry, Higgs Boson, Standard model of electroweak interaction-construction of Lagrangian SU(2) x U(1) group, extension of standard model to include quarks (qualitative).

[14 lecture hours]

Quantum Choromodynamics:

Theory of strong interaction, introduction of colour degree of freedom, quantum chromo dynamics (QCD), gluons, running coupling constant and asymptotic freedom.

[12 lecture hours]

Introduction to Particle Physics Experiments:

Experimental verification of the Standard Model and its particle content, Experimental state-of-the-art techniques used in today's experiments: Collider-based experiments and Astro-particle physics experiments, Particle Acceleration Mechanism and Modern Detectors, Prospects for discoveries of new phenomena: Glimpse of LHC-experiments, future Linear Collider experiments, India-based Neutrino Oscillation experiments

[8 lecture hours]

Quark Gluon Plasma:

Brief review, Experimental indication, equation of states, heavy meson properties in QGP, Some aspects of QGP related to astrophysics.

Reference Books

1. Introduction to Elementary Particles: David Griffiths
2. An introduction to Quarks and Partons: F.E. Close.
3. Introduction to Gauge Field Theories: M. Chaichian and N.F. Nelipa.

Paper Name: **HIGH ENERGY PHYSICS LAB I**
Paper Code: **PHY22429**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Equip students with hands-on experience in detecting and studying cosmic rays and their properties.
2. Enhance understanding of statistical methods in analyzing cosmic ray data.
3. Develop skills in utilizing various detection techniques and instruments for radiation measurement.
4. Foster critical thinking and analytical skills through experimentation and data interpretation.

Course Outcomes:

1. **CO1: Recall** the fundamental principles of cosmic ray detection, Geiger-Müller tubes, and radiation physics.

2. **CO2: Explain** the working principles and characteristics of radiation detection instruments, including scintillating tiles and Geiger-Müller tubes.

3. **CO3: Perform** experiments to detect cosmic rays, evaluate detector efficiency, and measure cosmic ray flux as a function of altitude and zenith angle.

4. **CO4: Analyze** experimental data to determine beta particle range, maximum energy, and the validity of the inverse square law for gamma rays.

5. **CO5: Evaluate** the efficiency, limitations, and accuracy of detection methods in studying cosmic rays and radiation interactions.

6. **CO6: Design** innovative experimental setups to improve detection methods and explore advanced applications of radiation physics and cosmic ray studies.

Catalogue Description:

Experimental Techniques in High-Energy Nuclear and Particle Physics is a compilation of the ingenious methods developed for experimentation in modern nuclear and particle physics. This course will provide a balanced view of the major tools and technical concepts currently in use, and elucidates the basic principles that underly the detection devices. The students will be involved in the planning of the experiment, learning the relevant techniques, setting up and troubleshooting the measuring apparatus, calibration, data-taking and analysis

Course Content:

Experiment I: Study the Statistical Properties of Cosmic Rays

Experiment II: Detection of Cosmic Rays using a System Composed of Three Plastic Scintillating Tiles

Experiment III: Evaluation of Detection Efficiency of Scintillating Tiles using Cosmic Muon

Experiment IV: Measurement of Zenith Dependence of Cosmic Ray Flux as a function of Altitude

Experiment V: Study of Characteristics of a Geiger Muller Tube

Experiment VI: Prove Inverse Square Law for Gamma Rays

Experiment VII: To Study Determination of Beta Particle Range and Maximum Energy (By Half Thickness Method)

Experiment VIII: To Study Back Scattering of Beta Particles

Paper Name: **HIGH ENERGY PHYSICS LAB II**
Paper Code: **PHY22444**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Equip students with fundamental numerical methods essential for solving computational problems in physics.
2. Enhance data analysis skills, focusing on error classification, propagation, and interpretation.
3. Introduce advanced programming tools and techniques relevant to high energy physics, particularly in Python.
4. Foster critical thinking and problem-solving abilities through the application of numerical methods and data analysis.

Course Outcomes:

1. **CO1: Recall** numerical methods for solving equations, performing interpolations, and evaluating derivatives and integrals.

2. **CO2: Explain** sources of computational errors, error propagation, and statistical methods for data analysis, including Monte Carlo techniques and Bayesian approaches.

3. **CO3: Apply** numerical techniques to solve linear and non-linear equations, differential equations, and partial differential equations.

4. **CO4: Analyze** experimental and simulated data using statistical tools like curve fitting, least squares, confidence limits, and advanced programming libraries (e.g., Python and ROOT).

5. **CO5: Evaluate** the accuracy and reliability of numerical methods and programming approaches in solving physics problems and data interpretation.

6. **CO6: Design and implement** short simulation projects using advanced programming tools and techniques, demonstrating problem-solving and code optimization skills.

Catalogue Description:

This course aims to familiarize the students with various data analysis techniques. Students will also be able to learn about how to apply various numerical methods and techniques to solve physical problems.

Course Content:

Numerical methods:

Introduction and sources of computational errors, solution of non-linear equations (Root finding), solution of system of linear equations, numerical interpolation, numerical differentiation and integration, solution of differential equations, solution of partial differential equations.

Data analysis:

Classification of errors, error propagation, curve fitting, least square methods, Confidence limit, basics of Monte Carlo techniques, data interpretation using Bayesian approach.

Advanced tools for High Energy Physics:

Basic ideas and concepts, Python Programming: Basic concepts, Input/output, Exception, Idiomatic usage, Object Oriented Programming, Introspection, Important Libraries, ROOT and its usage, Basic concepts, Root Files and Input/Output, Math Libraries, Histograms, Graphs, Trees, Statistical Analysis.

Short projects:

Short simulation projects should be given to each student. These will be assignment jobs. Class teacher can guide them in writing codes and ways to improve the codes.

Reference Books:

1. Lecture material will be provided by the course instructor.

Specialization: ***Biomedical Instrumentation***

Paper Name: **ANATOMY AND PHYSIOLOGY**
Paper Code: **PHY21417**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Provide an understanding of the basic anatomical and physiological concepts of the human body.
2. Explore the structure and function of various systems in the human body, including the cardiovascular, respiratory, musculoskeletal, nervous, digestive, and excretory systems.
3. Integrate knowledge of cellular and tissue functions with the functioning of organs and systems.
4. Develop critical thinking skills by applying physiological principles to understand human health and disease.

Course Outcomes:

1. **CO1: Define and describe** the basic anatomical and physiological features of the human body, including cells, tissues, and organ systems.

2. **CO2: Explain** the principles of cardiovascular and respiratory system functions, including blood flow, breathing mechanics, and gas exchange.

3. **CO3: Demonstrate** the application of mechanical and physiological principles in understanding musculoskeletal movements, gait cycles, and neuromuscular interactions.

4. **CO4: Analyze** the structural and functional relationships within the nervous system and sensory organs to interpret their physiological roles.

5. **CO5: Evaluate** the processes involved in digestive and excretory systems, including chemical digestion, absorption, and urine formation, to assess their efficiency and impact on human health.

6. **CO6: Integrate** knowledge of human physiology and anatomy to design hypothetical models or approaches to solve biomedical challenges, considering societal and ethical constraints.

Catalogue Description

The core-course of 'Anatomy and Physiology' will help to understand the classification and differences between different human organ systems. This course includes comprehensive approach through studying different techniques of identifying the possible cause of a physiological disorder. Furthermore, the molecular mechanisms of the muscle contraction, nervous stimulation and other physiological processes are included. All the lectures will be devoted on discussions of basic theories and advanced topics, focusing on practical implementation of knowledge. Classes will be conducted by lecture as well as power point presentation, audio visual virtual lab session as per requirement. The tutorials will enable the students with problem-solving ability led by the course coordinator. Students will perceive the basic concepts of the subject via exercise and discussions with the coordinator.

Course Content

[10 lecture hours]

Organization of Human Body

Anatomical position, terminology, regions and planes. Basic anatomy and physiology of cells, Tissues (epithelial, connective, muscle, nervous, blood, glands), Permeability of cell membrane, genesis of membrane potential, excitation of cell, Introduction to Cellular-sub-cellular structure and function, extra cellular matrix, tissues, organs and systems from an integrated viewpoint. Cell mediated immune response, Immune cell types.

[10 lecture hours]

Cardiovascular and respiratory system

Simple fluid dynamic characteristics of the body, descriptions of blood-flow in the arteries and veins and air-flow in the lungs, Functions of circulatory system, Heart structures (chambers, valves, and vessels), Circulatory routes (systemic, pulmonary, coronary and hepatic portal), Blood components, function and typing, Blood clotting, Regulation and conduction. General structure of respiratory system and functions, Functional aspects and mechanics of respiration, Mechanics and regulation of breathing, Gas exchange and gas laws, Hypoxia, effect of exercise.

[10 lecture hours]

Musculoskeletal System

Functions of skeletal and muscular system, The structural characteristics of human bones, mechanical functions of the skeleton and musculature, Physiology of muscle contraction, Filament Model, Neuromuscular junction, Structural and functional classification of joints, Types of movements, gait cycle.

[12 lecture hours]

Brain and sensory organs

Functions of nervous system, Nerve cell anatomy, Neural physiology (action potential, synaptic transmission, Na/K pump), Brain anatomy and hemispheres, action areas of different parts of the brain, Sensory motor nervefunctions, Basic anatomy of special senses: Eye, Ear, Tongue, Nose and Skin, Properties and functions of nervous system with respect to sensory organs.

[8 lecture hours]

Digestive and excretory system

Functions of digestive organs, Modes of mechanical digestion, Chemical digestion (hormones, enzymes, pH), Absorption and elimination, parts of GI Tract and accessory organs, Functions of excretory system, Kidney, ureter, bladder, urethra, Microanatomy and function of nephron, Formation of urine-steps involved.

Reference book:

1. Guyton, A.C. and Hall, J.E. (2006). Textbook of Medical Physiology. XI Edition. Hercourt AsiaPTE Ltd. /W.B. Saunders Company.
2. Tortora, G.J. and Grabowski, S. (2006). Principles of Anatomy and Physiology. XI Edition. Johnwiley and sons,Inc.
3. Human Anatomy and Physiology, Ross and Wilson
4. Tortora, G.J. and Grabowski, S. (2006). Principles of Anatomy and Physiology. XI Edition. John Wiley and sons, Inc.

Paper Name: **BIO INSTRUMENTATION AND MEDICAL PHYSICS**
Paper Code: **PHY21422**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Provide foundational knowledge of biomedical signals and their significance in medical instrumentation.
2. Explore various diagnostic and therapeutic instruments used in clinical settings.
3. Understand the principles and practices of radiation protection in medical applications.
4. Introduce advanced instruments and prosthetics, highlighting their design and functional aspects in patient care.

Course Outcomes:

1. **CO1: Recall** the principles and components of biomedical signals, recording systems, and diagnostic instruments, including sources of bioelectric signals and diagnostic tools.

2. **CO2: Explain** the working principles and applications of therapeutic instruments, including pacemakers, defibrillators, and surgical diathermy machines.

3. **CO3: Demonstrate** the use of diagnostic and therapeutic radiation instruments while adhering to radiation protection standards.

4. **CO4: Analyze** the operation and design constraints of advanced instruments like ultrasound systems, haemodialysis machines, and prosthetics.

5. **CO5: Evaluate** diagnostic and therapeutic systems, such as spirometers and oximeters, in terms of efficiency, accuracy, and safety for clinical applications.

6. **CO6: Design** innovative solutions for biomedical challenges, such as neural prostheses or advanced diagnostic tools, considering ethical, societal, and sustainability factors.

Catalogue Description:

Bioinstrumentation and Medical Physics is an interdisciplinary course which is based on the understanding the physics behind working principle of different medical devices. In this course, different aspects of designing and development of diagnostic and therapeutic devices are explained in depth. Furthermore, diagnostic and therapeutic radiation devices and radiation protection is also introduced as a part of medical physics. Through this course, students will be guided to apply the knowledge of instrumentation towards the development and maintenance of medical devices used to provide healthcare support to the human beings. The tutorials will enable the students with problem-solving ability led by the course coordinator. Students will perceive the basic concepts of the subject via exercise and discussions with the coordinator.

Course Content

[15 lecture hours]

Biomedical Signals, Electrodes and recording systems

Sources of biomedical signals, basic medical instrumentation system, PC based medical instruments, General constraints in design of medical instrumentation systems, origin of bioelectric signals, Electrocardiogram (ECG) -block diagram, ECG leads, effects of artifacts, multi-channel, ECG machine, Phonocardiograph-origin of heart sounds, microphones and amplifiers for PCG, Electroencephalogram (EEG) - block diagram, computerized analysis of EEG, Electromyogram (EMG), Myoelectric control, Voluntary control of myoelectric signals, use of myoelectric signal for control - signal processing and recording, biofeedback instrumentation. Electrooculogram (EOG), Electroretinogram (ERG), Recording Electrodes – Electrode-tissue interface, polarization, skin contact impedance, motion artifacts, Silver-Silver Chloride electrodes, Electrical conductivity of electrode jellies and creams, microelectrodes, Stimulations and Recording electrodes, Amplifiers, Analysis and storage: Measurement of average auditory evoked potential - application - visual evoked potential measurement and application.

[10 lecture hours]

Diagnostic Instruments

Oximetry- In-vitro and in-vivo, ear oximetry, pulse oximetry, skin reflectance oximeters, intravascular oximeter. Electromagnetic blood flowmeter- principle, square wave electromagnetic flowmeter, Doppler shift ultrasonic flowmeter, flow measurement by Doppler imaging, NMR and Laser Doppler flowmeter, Cardiac output measurement- Indicator and dye dilution technique, impedance method, ultrasound method. Pulmonary function measurement measurements-respiratory volumes and capacities, compliance and related pressures, dynamic respiratory parameters, basic spirometer, ultrasonic spirometer, pneumotacometer- Fleishand turbine type, measurement of volume-flow volume curve, nitrogen washout technique, detection of physiological activities using impedance techniques - impedance plethysmography

[12 lecture hours]

Therapeutic Instruments

Need for cardiac pacemaker, external pacemaker, implantable pacemakers-types, ventricular synchronous demand pacemaker, programmable pacemaker, power sources for implantable pacemakers. Need for defibrillator, DC defibrillator, automatic external defibrillator, implantable defibrillators, Principle of surgical diathermy and surgical diathermy machine, Electrotherapyfunctional block diagram and working, Anesthesia-Need for anesthesia, delivery of anesthesia, anesthesia machine, Ventilator – types, controlling parameters, working principle.

[15 lecture hours]

Diagnostic and therapeutic radiation and radiation protection

Basic Physics of diagnostic radiology – Production of X-rays - diagnostic X-ray tube andits electrical circuits- X-ray tube rating - X-ray film, properties and Processing -Intensifying screens - Factors affecting radiographic imaging
Radiation units exposure, absorbed dose, units: rad, gray, relative biological effectiveness, effective dose- Rem and Sievert, inverse square law. Radiation Detectors: ionization (Thimble chamber, condenser chamber), chamber. GeigerMuller counter, Scintillation counters and Solid-State detectors, TFT.
Basic concepts of Radiation protection standards - philosophy behind radiationprotection - External radiation protection - ICRP recommendations - Radiation doselimits - system of radiological protection - Equivalent dose, effective dose, committeddose - radiation exposures

[10 lecture hours]

Advanced Instruments and Prosthetics

Artificial kidney-Principle and haemodialysis machine. Production and properties of ultrasound - propagation of ultrasound through body tissue, Acoustic impedance, ultrasound scanning modes, Doppler effect, Double doppler shift, doppler systems, ultrasonic tomography - applications of ultrasound in medicine. Introduction to prosthetics, Types of prostheses and their recent developments, Upper limb and Lower limb prostheses, Neural prostheses, Material selection and design challenges

Reference Books

1. Hand Book Of Biomedical Instrumentation, Khandpur
2. Fundamentals of Bio-medical engineering, G. S. Sawhney.
3. Medical Instrumentation: Application and Design, John G. Webster

Paper Name: **BIOMEDICAL SPECTROSCOPY AND MEDICAL IMAGING TECHNIQUE**
Paper Code: **PHY21433**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Provide an understanding of various medical imaging modalities and their principles.
2. Explore image fundamentals and the physics behind imaging techniques.
3. Develop skills in image processing, analysis, and classification for improved diagnostic capabilities.
4. Introduce spectroscopic techniques and their applications in biomedical diagnostics.

Course Outcomes:

1. **CO1: Recall** the principles and techniques of various medical imaging modalities such as CT, MRI, PET, and ultrasound imaging.

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

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

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

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

6. **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.

Catalogue Description:

Biomedical Spectroscopy and Medical Imaging Technique is an interdisciplinary course which is based on the understanding the light matter interaction required in spectroscopic techniques and medical imaging. In Biomedical Spectroscopy and Medical Imaging Technique, different aspects of spectroscopic characterization of biomolecules are explained in depth. The students opting for this course gets a complete knowledge about the medical images obtained through X ray, CT, MRI, etc and their processing techniques which can improve the image quality for better interpretation. Through this course, students will be guided to apply the knowledge of image processing techniques towards development and improvement of software in medical imaging devices used to provide automation in diagnosis of diseases.

Course Content

[20 lecture hours]

Medical Imaging Modalities:

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 Nuclear Magnetic Resonance (NMR) imaging and its application in the field of diagnostics. 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. Physics of ultrasound imaging, uses in diagnosis, Image quality description and patient risk, Theory and applications of optical, thermography imaging.

[6 lecture hours]

Image Fundamentals:

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.

[10 lecture hours]

Image processing, analysis and classification:

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.

[10 lecture hours]

Reconstruction of CT and MRI Images:

Reconstruction of CT and MRI Images: Image reconstructions from projections-radon transforms, filter back projection algorithm, algebraic methods ,3D tomography, imaging methods of CT images, imaging methods in magnetic resonance imagers, Fourier reconstructions of Magnetic resonance images.

[7 lecture hours]

Transmission of Medical Images:

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

[12 lecture hours]

Spectroscopic Techniques:

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.

Reference Books:

1. Hand Book of Biomedical Instrumentation, Khandpur
2. Fundamentals of Medical Imaging, Paul Suetens.
3. Digital image processing using Matlab, R. C. Gonzalaz, Richard. E. Woods, Steven L Eddins
4. Biomedical Application of Spectroscopy, R.J.H Clark.

Paper Name: **BIOSENSORS AND LASER IN MEDICAL APPLICATION**
Paper Code: **PHY21438**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Equip students with knowledge about various measurement techniques and sensors used in medical and engineering applications.
2. Explore the principles and applications of temperature measurement, chemical sensors, and MEMS technology.
3. Understand the optical properties of tissues and the applications of lasers in medicine.
4. Provide awareness of laser safety regulations and practices**.**

Course Outcomes:

1. **CO1: Identify** the principles and applications of displacement, motion, and pressure measurement devices such as strain gauges, LVDTs, and piezoelectric transducers.

2. **CO2: Explain** the working mechanisms of temperature and chemical sensors, including thermistors, thermocouples, potentiometric sensors, and fiber optic sensors.

3. **CO3: Apply** MEMS technology concepts to design and simulate microsensors and integrated smart systems for biomedical applications.

4. **CO4: Analyze** the optical properties of tissues using experimental methods for reflectance, transmittance, and absorption, and evaluate laser systems in medicine and biology.

5. **CO5: Evaluate** the use of lasers in surgical applications and therapeutic procedures, including cancer surgery, endoscopy, and genetic engineering, for efficiency and safety.

6. **CO6: Design** laser safety protocols addressing eye, skin, electrical, and fire hazards, incorporating technical and non-technical measures to ensure compliance with regulations.

Catalogue Description

This course provides a broad overview of optical fiber sensing principles and techniques used for biological and medical applications. Besides sensors, other uses of specialty optical fibers for biomedical devices—such as endoscopes, imaging, and laser delivery, among others—will be briefly covered.

Course Content

[8 lecture hours]

Displacement, motion and Pressure Measurement: (with applications):

Resistive: Potentiometers, Strain Gauges and Bridge Circuits. Inductive: Variable Inductance and LVDT Capacitive type, Piezoelectric Transducers. Types of Diaphragms, Bellows, Bourdon Tubes.

[7 lecture hours]

Temperature Measurement:

Thermistor, Thermocouple, Resistive Temperature Detector, IC based Temperature Measurement Radiation Sensors.

[8 lecture hours]

Chemical Sensors:

Blood gas and Acid- Base Physiology, Potentiometric Sensors (pH, pCO2 Electrodes, Amperometric Sensors (pO2), ISFETS, Transcutaneous Arterial O2 and CO2 Tension Monitoring. Fiber Optic Sensors: Principle of Fiber Optics, Fiber Optic Sensors - Temperature, Chemical, Pressure. Biosensor: Classifications and types with examples.

[8 lecture hours]

MEMS technology:

An introduction to Micro sensors and MEMS, Evolution of Micro sensorsand MEMS, Micro sensorsand MEMS applications, Microelectronic technologies for MEMS, Micromachining Technology, Surface and Bulk Micromachining, Micro machined Micro sensors, Mechanical, Inertial, Biological, Chemical, Acoustic, Microsystems Technology, Integrated Smart Sensors and MEMS, Interface Electronics for MEMS, MEMS Simulators, MEMS for RF Applications, Bonding and Packaging of MEMS.

[8 lecture hours]

Optical properties of tissues (normal and tumor):

Experimental methods to determine the reflectance, transmittance, absorption and emission properties of tissues. Laser systems in medicine and biology - Nd-YAG, Ar ion, CO2, Excimer - Gold vapor laser - beam delivery system and control.

[7 lecture hours]

Surgical Applications of Lasers:

Evaporation and excitation techniques - sterilization - hemostasis - laryngeal surgery - cancer surgery - liver surgery - stomach surgery - gynaecological surgery - urological surgery - cardiac surgery- lasers in Opthalmology – Dermatology and Dentistry – cosmetic surgery.

[7 lecture hours]

Lasers in Diagnosis and Therapy:

Trace elements detection - laser induced fluorescence studies - cancer diagnosis - photo radiation therapy of tumors - lasers in endoscopy – lasers in laproscopy – lasers in trapping of cells and genetic engineering - biosimulation.

[8 lecture hours]

Laser Safety Regulations:

Basic laser safety – eye hazards – skin hazards – electrical hazards – fire and flood hazards – laser safety classes – technical precautions – nontechnical measures – laser safety regulations – common obstacles – laser medical surveillance.

Reference Books:

1. Yoon, Jeong-Yeol. *Introduction to biosensors: from electric circuits to immunosensors*. Springer, 2016.
2. Sadana, Ajit, and Neeti Sadana. *Handbook of biosensors and biosensor kinetics*. Elsevier, 2010.
3. Turner, Anthony, Isao Karube, and George S. Wilson. *Biosensors: fundamentals and applications*. Oxford university press, 1987.
4. Jelínková, Helena, ed. *Lasers for medical applications: diagnostics, therapy and surgery*. Elsevier, 2013.
5. Wieneke, Stephan, and Christoph Gerhard. *Lasers in Medical Diagnosis and Therapy*. London, UK: IOP Publishing Ltd, 2018.

Paper Name: **SENSOR AND MEDICAL INSTRUMENTS LAB**
Paper Code: **PHY22428**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Familiarize students with the operation and calibration of various medical devices used for physiological measurements.
2. Provide hands-on experience in conducting experiments related to bio-signals and measurements.
3. Develop analytical skills for interpreting data collected from medical instrumentation.

Course Outcomes:

1. **CO1: Identify** the principles and working mechanisms of biomedical devices such as EEG, ECG, pulse oximeters, and audiometers.

2. **CO2: Explain** the calibration and operation of diagnostic instruments, including sphygmomanometers and spirometers.

3. **CO3: Perform** experiments with biomedical devices to collect, analyze, and interpret physiological data.

4. **CO4: Analyze** the performance of sensors and transducers, and evaluate their role in biomedical instrumentation.

5. **CO5: Evaluate** the accuracy and reliability of measurements from devices such as glucometers and pulse oximeters, ensuring compliance with safety standards.

6. **CO6: Design and implement** experimental procedures to test and calibrate biomedical equipment, considering real-world constraints and ethical practices.

Course Description:

This course aims to impart knowledge of the working principles of different biomedical instruments experimentally. The course is designed to introduce various biomedical sensors to the students. In this course students will perform experiments to determine the physiological parameters of human body such as SpO2, Heart rate, body temperature, etc. The students will also observe ECG and EEG recorded from human subjects. The course will consist of practical classes and demonstration of theories of relevant experiments. We mainlyfocus on the development of fundamental concepts of bioinstrumentation which could be helpful in future to solve various real life problems associated with healthcare. Apart from regular class on experiments some special classes will be arranged for student presentations.

Course Content:

Experiment 1: Experiments and calibration with EEG machine.

Experiment 2: Experiments and calibration with ECG machine.

Experiment 3: Experiments with Pulse-oximeter machine.

Experiment 4: Experiments with Audiometer.

Experiment 5: Sensor and Transducer Lab.

Experiment 6: Experiment and calibration of Sphygmomanometer.

Experiment 7: Experiments with glucometer.

Experiment 8: Experiments for measuring pulmonary functions with spirometer.

Reference Books

The Manuals are provided in Lab for respective experiments. Students are also encouraged to do research from different open access materials available in internet.

Paper Name: **MICROPROCESSOR AND IMAGE PROCESSING LAB**
Paper Code: **PHY22443**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. To understand and apply the fundamental principles of digital data representation and manipulation through binary arithmetic.
2. To develop proficiency in image processing techniques, including enhancement, filtering, and segmentation.
3. To engage in practical programming exercises that reinforce theoretical knowledge in digital image processing.
4. To cultivate problem-solving and analytical skills through the implementation of algorithms in various image processing tasks.

Course Outcomes:

1. **CO1: Recall** the principles of data storage, arithmetic operations, and memory management in programming.

2. **CO2: Explain** the concepts and techniques of histogram equalization, gray-level transformation, and image filtering in spatial and frequency domains.

3. **CO3: Implement** programs to perform basic arithmetic operations, including addition, subtraction, multiplication, and division, with 16-bit and 8-bit data, and store results in memory.

4. **CO4: Analyze** the effects of spatial and frequency domain filters on images and their role in enhancing visual features.

5. **CO5: Evaluate** the effectiveness of image segmentation techniques in isolating regions of interest for various applications.

6. **CO6: Design and optimize** algorithms for advanced image processing tasks, such as segmentation and histogram equalization, considering performance and accuracy.

Course Description:

This course aims to impart knowledge on the various computational techniques for handling, identifying and improving medical images taking for diagnostic and therapeutic purposes. The course is designed to introduce microprocessor fundamentals and image processing techniques such as filtering, smoothing, enhancing, identifying region of interest, etc. The students will be able to process X-ray, CT scan or MRI images and also convert colour images to grey scales for quantification. We mainly focus on the development of fundamental concepts of digital image processing which could be helpful in future to solve various real life problems associated with medical imaging. Apart from regular class on computation some special classes will be arranged for student presentations.

Course Content:

Experiment 1: Addition and subtraction of Two 16 bit data and store the result in Memory.

Experiment 2: Multiplication and division of two 8 bit numbers and store the result in memory address.

Experiment 3: Program to show histogram equalization effect for an image

Experiment 4: Programs for image gray-level transform.

Experiment 5: Programs for image filtering in spatial domain.

Experiment 6: Programs for image filtering in frequency domain.

Experiment 7: Program for image segmentation

Specialization: ***Biophysics***

Paper Name: **MOLECULAR BIOPHYSICS**
Paper Code: **PHY21419**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To understand the fundamental concepts of atomic and molecular structures, including bonding and interactions between atoms and molecules.
2. To explore the laws of thermodynamics and their applications in biological systems, focusing on energy transformations and entropy.
3. To examine bioenergetics and the biochemical processes involved in energy generation and transfer in living organisms.
4. To analyze the principles of redox reactions and their significance in biological systems, along with the molecular building blocks of life.

Course Outcomes:

1. **CO1: Recall** the atomic and molecular structures, bonding mechanisms, and molecular orbital theories relevant to biological systems.

2. **CO2: Explain** the principles of thermodynamics, including free energy, entropy, and heat content, with applications to living systems and food energy measurement.

3. **CO3: Apply** the concepts of bioenergetics to analyze energy generation and transfer processes, including glucose metabolism and ATP formation.

4. **CO4: Analyze** redox potentials in biological systems using Nernst equations and evaluate the equivalence of electrical and chemical energy.

5. **CO5: Evaluate** the properties and classifications of amino acids, peptides, and nucleotides, highlighting their role as molecular alphabets of life.

6. **CO6: Design** models to represent the structural and functional relationships among biomolecules, including amino acids, nucleic acids, and lipids, for advanced biochemical applications.

Catalogue Description:

The course focuses on the application of selected topics within physics to describe the molecular properties of biological molecules and biopolymer assemblies, and some of the most commonly used techniques for the determination of these properties.

Course Content:

[12 lecture hours]

Atomic and Molecular Structures:

Structure of Atom, Quantum numbers, Pauli's exclusion principle, Hund's rule, Periodic table, Bonds between atom and molecules, Ionic, Covalent, Hydrogen, Electrostatic, Di-sulphideand Peptide bonds, Vander waals forces, Bond energies, Bond angles, Bayer's strain, Weak interactions, Molecular orbital theories, Hybridization of orbitals, J and K bonds.

[10 lecture hours]

Thermodynamics:

Laws of Thermodynamics, Concept of free energy, Unavailable energy and Entropy, Negative entropy change in living system, Heat content of food, Measurement of heat content, Bomb calorimeter.

[10 lecture hours]

Bioenergetics

Energy generation and energy transfer processes in biochemical reactions, Metabolism of glucose and formation of ATP. Energy requirements in cell metabolism, Role and Structure of mitochondria, High-energy phosphate bond, Electron transfer phenomenon and biological energy transfer.

[11 lecture hours]

Redox Potentials

Oxidation and Reduction, Equivalence of electrical and chemical energy, Electro chemical cell, Contact potentials, Galvanic cell, Potential of half-cell, Redox potentials and its calculations by Nernst equation, Examples of Redox Potential in biological system.

[12 lecture hours]

Molecular alphabets of Life

Amino acid, Nucleic acid bases and Lipids, Classification and Properties of Amino acid, Peptides and Polypeptides, Nucleosides, Nucleotides, Polynucleotides, Pentose and Hexose Polysaccharides, Amino acid to Peptides, Polypeptides, Different types of linkages.

Reference books:

1. Stanford J.R. (1975), Foundation of Biophysics, Academic press.
2. Ackerman E.A. Ellis, L.E.E. and Williams L.E. (1979), Biophysical Science, Prentice-Hall Inc.
3. Hughes W. (1979), Aspects of Biophysics, John willey and sons.
4. Bulterl.A.V. And Noble D.Eds. (1976), Progress in Biophysics and Molecular Biology (all volumes) Pergamon, Oxford.
5. Casey E.J. (1967), Biophysics, concepts and mechanisms. Affiliated East west press.
6. De Robertis E.D.P. and De Robertis E.M.P. (1981), Essentials of cell and molecular Biology, Holt sounders International Editions.
7. Haschemyer R.N. and Haschemyer A.E.B.V. (1973), Proteins, John willey and sons.
8. Pullman B. (1978), Molecular Association in Biology, Academic Press.
9. Quagliokiello E., Palmieri F. and singer, T.P. (1977), Horizons in Biochemistry and Biophysics (all volumes) Addison Wesley Publishing Company.

Paper Name: **CELLULAR BIOPHYSICS**
Paper Code: **PHY21424**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To understand the fundamental organization and functions of prokaryotic and eukaryotic cells, including their internal structures and organelles.
2. To explore the tools and techniques used in cell biology for studying cellular structures and functions.
3. To analyze the processes of cell growth, division, and the molecular mechanisms regulating the cell cycle.
4. To investigate the mechanisms of cell-cell interactions and signaling pathways that regulate cellular behavior and differentiation.

Course Outcomes:

1. **CO1: Recall** the structure, organization, and functions of prokaryotic and eukaryotic cells, including cell organelles and their interactions with the environment.

2. **CO2: Explain** the design and working principles of advanced tools in cell biology, such as light and electron microscopes, cyto-photometry, and flow cytometry.

3. **CO3: Apply** concepts of cell growth and division to analyze the molecular mechanisms of the cell cycle, mitosis, meiosis, and apoptosis.

4. **CO4: Analyze** cell-cell interactions, including the roles of glycocalyx, extracellular matrix, cell junctions, and signaling pathways in cellular communication and adaptation.

5. **CO5: Evaluate** the molecular mechanisms and morphological movements involved in cell differentiation, including cytoplasmic determinants, positional values, and the maintenance of the differentiated state.

6. **CO6: Design** experimental frameworks to study cell signaling, cell differentiation, and cell cycle regulation, incorporating tools like flow cytometry and advanced microscopy.

Catalogue Description:

A physicist's perspective on the building blocks of the living world, such as nucleic acids, proteins and lipids. The course will cover topics such as symmetry, structural complexity of the biological macromolecules, molecular interactions in the cellular environment and the impact for the biological function. Basic concepts from mechanics and thermodynamics will be applied specifically to proteins and DNA in order to understand structural transitions, stabilizing interactions, reaction dynamics and equilibrium. A rigorous treatment of a wide range of biophysical techniques commonly use in life science, such as optical spectroscopy, light scattering, mass spectrometry and single molecule methods, will be accompanied by recent examples from biophysics research

Course Content:

[7 lecture hours]

Cell Organization and Function:

Cell as the basic structural unit, Origin and organization of Prokaryotic and Eukaryotic cell, Cell sizeand shape, Fine structure of Prokaryotic and Eukaryotic cell organization (Bacteria, Cyanobacteria, plant andAnimal cell), Internal architecture of cells, cell organelles, compartment and assemblies membrane system, Ribosome, Polysomes, Lysosomes and Peroxisomes, Connection between cell andits environment, Glycocalyx, Extracellular Matrix.

[10 lecture hours]

Tools in Cell Biology:

Light microscopy – Design and working of Compound, Phase contrast, Interference, Dark fieldPolarizing and Fluorescence microscope, Electron microscopy – Design and working of ScanningElectron Microscope (SEM), Transmission Electron Microscope (TEM), Cyto-photometry, Flowcytometry and cell sorting, autoradiography, Cell disintegration methods.

[10 lecture hours]

Cell Growth and Division

Kinetics of cell growth, The Cell Cycle, Interphase-G1, S, G2, M molecular events at different cellcycle phases, A cytoplasmic clock times, cell cycle in early embryogenesis, Polypeptide GrowthFactors andControl of cell proliferation, Mitosis and Cell division- Molecular mechanism, Events inmitosis, Role of mitotic apparatus, Meiosis and Sexual reproduction, Molecular mechanism ofmeiosis, DNA metabolism during meiosis, Dividing and Non-dividing cells, Synchronization of cellcycles, Cell aging and death-Apoptosis, Cell Cycle Control, Roleof MPF, Cd2 Proteins and G-1 Cyclins.

[12 lecture hours]

Cell-Cell Interaction

Connection between the cell and its environment, Glycocalyx, Extracellular Matrix, collagen,Elastin, Fibronectin, Lamin, Proteoglycans, Integrins, Cell Junctions, Desmosomes, Gap junction,Tight Junctions, Plasmodesmata, Synapse and synaptic vesicles, Cell Signaling, General principleof cell signaling, Paracrine, Autocrine, Endocrine andsynaptic signaling, Heat Shock Proteins, G-Proteinstructure and role in signaling, Intracellular Cyclic AMP, Role Ca^{++} in cell signaling, CAM Kinases, (Calmodulin/Ca++ dependent protein kinases), Interaction between cyclic AMP andCa++. Role of Methylation in adaptation and bacterial chemotaxis.

[12 lecture hours]

Cell differentiation

General characteristics of cell differentiation, Localization of cytoplasmic determinants, Molecular mechanism of cell differentiation, Morphological movements and the shaping of body plains, Cell memory, Concept of positional values, maintenance of differentiaed state, Tissue with permanent cells, neuronal networks and centre of the lens of adult eye.

Reference Books:

1. Berns M.W. (1982), Cells, Holt Sounders International Editors.
2. Bulterl.A.V. And Noble D.Eds. (1976), Progress in Biophysics and Molecular Biology (all volumes) Pergamon, Oxford.
3. Lehninger A. (1981), Biochemistry, Butter Worth Publication.
4. Cantor C.R. and Schimmel P.R. (1980), Biophysical chemistry, W.A.Fremman and Co.
5. De Robertis E.D.P. and De Robertis E.M.P. (1981), Essentials of cell and molecular Biology, Holt sounders International Editions.
6. Dickerson R.E.and Geis I. (1972), Proteins: structure, function and evaluation, Benjamin.
7. Jain M.K. and Wanger R.C. (1980), Introduction to Biological Membranes, John willey and sons.
8. Sheelk P. and Birch D.E. (1983), Cell Biology Structure, Biochemistry and function, John willey and sons.
9. Gerald Karp (1996), Cell and Molecular biology concepts and experiments, John willey and sons, Inc.
10. Loewy Sickevitz, Menninger, Gallant (1991), Cell structure and function, Sounders college pub.
11.Khandpur R. S., Handbook of Biomedical Instrumentation, Tata McGraw-HillPublishing Co. Ltd.
12.Joseph J. Carrand John M. Brown, Introduction to Biomedical EquipmentTechnology, John Wiley and Sons.

Paper Name: **PHYSIOLOGY AND BIOPHYSICS**
Paper Code: **PHY21435**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To gain a foundational understanding of brain anatomy, neurophysiology, and the mechanisms of nerve impulse generation and transmission.
2. To explore the biophysical mechanisms behind sensory systems, including vision, audition, and other senses.
3. To comprehend the cardiovascular and pulmonary systems and the physiological responses to stress and physical demands.
4. To understand renal and reproductive physiology, as well as the effects of extreme environments such as high altitude, space, and deep-sea conditions.

Course Outcomes:

1. **CO1: Recall** the anatomy and neurophysiology of the brain, including the generation and propagation of nerve impulses, synaptic transmission, and neuronal networks.

2. **CO2: Explain** the biophysics of sensory mechanisms and the neurophysiology of special senses, including vision, audition, and sensory transduction processes.

3. **CO3: Apply** principles of cardiovascular and pulmonary physiology, including hemodynamics, respiratory mechanics, and gas exchange, to assess responses to stress and physical activity.

4. **CO4: Analyze** the biophysical aspects of renal and reproductive physiology, including filtration, osmolality, acid-base balance, and reproductive technologies.

5. **CO5: Evaluate** the physiological adaptations of the human body to extreme environments, such as high altitudes, space, and deep-sea conditions, and the associated challenges.

6. **CO6: Design** experimental frameworks and conceptual models to study neurophysiological processes, sensory systems, and physiological responses in specialized conditions.

Catalogue Description:

Physiology is the study of how biological systems act at the molecular, cellular and organ system level. Because a physiologist also explores normal human body function, research in physiology provides the basis for understanding the abnormal function seen in human disease (pathophysiology) and for developing new methods in treating diseases (translational research). Biophysicists use the methods of mathematics, physics and chemistry to study how living organisms work. Biophysicists study life at every level and ask questions such as: how the brain processes and stores information, how cells detect and respond to signals, how the heart pumps blood and how muscles contract.

Course Content:-

[10 lecture hours]

Brain and Neurophysiology:

General anatomy of brain, Central peripheral nervous system, Mylenatedandunmylenated nerve cells, Blood brain barrier generating nerve impulse, Synaptic transmission, Physicochemical basis of membrane potential, Resting and action potential, Propagation of action potential, Voltage clamp and patch-clamp techniques, Hadgkin-Huxley analysis, Motor and cortical control, Sleep and consciousness Neuromuscular junction, Excitation contraction coupling Neuronal networks, Processing of information, Memory and neuropeptides.

[10 lecture hours]

Special senses

Biophysics of sensory mechanism and function of receptor cells, Cutaneous, Olfactory and gustatory sensations, Vision. Physical aspects, Neurophysiology colour vision, Visual evoked potentials. Audition: - Physical aspects, auditory transduction, Acoustic encoding.

[10 lecture hours]

Cardiovascular and Pulmonary physiology

Physical characteristics of blood, Hemodynamics principles and equations, Genesis and spread of cardiac impulse, Cardio dynamics, Regulation of blood pressure and blood volume, Heart rate, Cardiac output and venous return, Cardiovascular responses to stress (exercise, shock andhypertension),Biophysical aspects of lung expansion respiratory mechanics and gas exchange process, Gas diffusion and transport, Pulmonary circulation and ventilation, Respiratory control andresponse to stress, Pulmonary function test and it’s significance.

[10 lecture hours]

Renal and Reproduction physiology

Ionic composition and distribution of body fluids, Body fluid osmolality dialysis anddehydration. Biophysical aspects of renal filtration and blood flow, Renal tubular function, Concepts effective circulation volume, Autoregulation, Reabsorption and secretion, Renal regulations of acid basebalance. Hormonal control of reproductive mechanisms, Morphology and dynamics of sperm, kinematics parameters of sperm movement and sperm motility, Basic principles of assisted reproductive technology- IUI, IVF techniques.

[5 lecture hours]

Aviation, High Altitude, Space and Deep-sea physiology

Effect of low oxygen pressure on body, mountain sickness, clinical lessons at high altitude, Effect of acceleratory forces on the body in aviation and space physiology. Radiation andtemperature, Problems at high altitude and space, weightlessness in space, Physiological adaptation to spaceflight. Physiology in deep sea diving and other high-pressure operations.

Reference Books:

1. Bulter.A.V. And Noble D.Eds. (1976), Progress in Biophysics and Molecular Biology (allvolumes) Pergamon, Oxford.
2. Casey E.J. (1967), Biophysics, concepts and mechanisms. Affiliated East west press.
3. Basar E. (1976), Biophysical and physiological system Analysis, Addition-Wesley.
4. Cameron J. R. and skofronick J.G. (1978), Medical Physics, John willey and sons.
5. Guyton A.C. (1981), Textbook of Medical Physiology, Sounders co.
6. Ruch J. and Patton H.D. (1973), Physiology and Biophysics (all volumes), W.B. soundersco.
7. M. M. Rehani (2000), Advances in Medical physics, Jaypee Brothers.

Paper Name: **BRAIN COMPUTER INTERFACE**
Paper Code: **PHY21440**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To understand the structure and function of neurons and the central and peripheral nervous systems.
2. To introduce brain recording and stimulation techniques and their specifications.
3. To apply signal processing techniques for analyzing neural signals.
4. To explore Brain-Computer Interfaces (BCIs) and their clinical applications.

Course Outcomes:

1. **CO1: Recall** the structure and function of neurons, synapses, and the central and peripheral nervous systems in controlling human activities.

2. **CO2: Explain** the principles of brain recording and stimulation techniques, including electrode types, recording devices, and neural stimulation methods.

3. **CO3: Apply** signal processing techniques such as Fourier Transform, PCA, and Support Vector Machines to analyze neural data for Brain-Computer Interfaces (BCIs).

4. **CO4: Analyze** the characteristics and applications of invasive, semi-invasive, and non-invasive BCIs for medical technology.

5. **CO5: Evaluate** the clinical applications of BCIs for different types of users, including the totally and partially disabled, while addressing ethical concerns.

6. **CO6: Design** innovative BCI systems integrating signal processing and neural stimulation technologies to address medical and accessibility challenges.

Catalogue Description:

Brain-computer is an interdisciplinary course which is based on the interpretation of brain signals through signal processing techniques and providing feedback for controlling external devices. This course will present some of the basic mathematics, neuroscience, and computational methods necessary to begin work in this emerging field. Statistical learning, Bayesian inference, dimensionality reduction, and information theory among other topics will be presented in the context of brain interfaces based on neural implants and EEG recordings. Novel interfaces, computational issues, and ethical considerations will also be addressed.

Course Content:

[10 lecture hours]

Basic Neuroscience

Structure of neurons, synapses, generation of action potential, nerve conduction, Central nervous system, peripheral nervous systems, organization of brain in controlling activities of human.

[8 lecture hours]

Recording and Stimulating the Brain

Types of electrodes for recording and stimulation, characteristic differences in recording and stimulation, types of neural stimulation, recording devices specifications.

[12 lecture hours]

Signal Processing

Feature Extraction Methods Time/Space Methods – Fourier Transform, Wavelets, AR, MA, ARMA models, Bandpass filtering, Template matching, Kalman filter, PCA, Laplacian filter – Linear and Non-Linear Features; Feature Translation Methods Linear Discriminant Analysis – Nearest neighbours, Support Vector Machines - Regression – Learning Vector Quantization – Gaussian Mixture Modeling – Hidden Markov Modeling – Neural Networks

[10 lecture hours]

Major Types of BCIs

Invasive BCIs, Semi-Invasive BCIs, Non-Invasive BCIs, Stimulating and Bidirectional BCIs. Application in medical technology.

[10 lecture hours]

BCI Clinical Applications and Ethics

Potential BCI users: totally disabled, partially disabled, disabled with sustained neuromuscular control; ethical issues with patients for recording data, acceptance of patients for uses of BCI.

Reference Books:

1. Jonathan Wolpaw,Elizabeth Winter Wolpaw,’Brain Computer Interfaces: Principles and practice”, Edition 1, Oxford University Press, USA, January 2012
2. Special Issue on Brain Control Interfaces, IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol 14, June 2006.
3. R. Spehlmann, “EEG Primer”, Elsevier Biomedical Press, 1981.
4. Bernhard Graimann, Brendan Allison, Gert Pfurtscheller, "Brain-Computer Interfaces:

Revolutionizing Human-Computer Interaction", Springer, 2010

5. Ali Bashashati, Mehrdad Fatourechi, Rabab K Ward, Gary E Birch," A survey of signal Processing algorithms in brain–computer interfaces based on electrical brain signals" JOURNAL OF NEURAL ENGINEERING, VOL.4, 2007, PP.32-57
6. Arnon Kohen, "Biomedical Signal Processing", Vol I and II, CRC Press Inc, Boca Rato, Florida.

Paper Name: **NUMERICAL METHODS AND PROGRAMMING LAB**
Paper Code: **PHY22445**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. To understand and apply numerical methods to solve algebraic and transcendental equations, perform curve fitting, and solve differential equations.
2. To introduce fundamental programming concepts using C and C++ for implementing numerical algorithms.
3. To explore modeling techniques in biosystems and use numerical methods to develop and simulate physiological models.
4. To gain practical experience with modeling tools such as MATLAB, LabVIEW, and COMSOL for solving complex biosystem-related problems.

Course Outcomes:

1. **CO1: Recall** the fundamental concepts of numerical analysis, computer programming, and modeling biosystems.

2. **CO2: Explain** numerical methods and their applications in solving algebraic, differential equations, and biosystem modeling challenges.

3. **CO3: Apply** appropriate computational tools, such as MATLAB, C/C++, and COMSOL, for modeling physiological systems and solving practical problems.

4. **CO4: Analyze** numerical errors, differentiate between various numerical methods, and select suitable approaches for solving linear and nonlinear systems.

5. **CO5: Evaluate** the efficiency and accuracy of different numerical methods and modeling tools to propose solutions to real-world biological and computational problems.

6. **CO6: Design** innovative computational models using MATLAB, LabVIEW, and COMSOL for simulating biological and physical systems under real-world constraints.

Catalogue Description:

This course provides an in-depth understanding of numerical methods and their applications in solving various mathematical problems, focusing particularly on biological system modeling. It introduces students to methods for determining roots, solving linear and nonlinear equations, curve fitting, and applying numerical differentiation and integration. In addition, the course explores the use of programming languages such as C and C++ to implement numerical algorithms and introduces mathematical modeling tools like MATLAB, LabVIEW, and COMSOL. These tools are essential for simulating physiological systems and solving differential equations pertinent to biosystems. Practical projects will allow students to apply these techniques to real-world biological problems, providing a hands-on experience in computational modeling.

Course Content

Numerical Analysis:

Approximations and round off errors, Truncation errors and Taylor Series, Determination of roots of polynomials and transcendental equations by Newton- Raphson, Secant and Bairstow's method. Solutions of linear simultaneous linear algebraic equations by Gauss Elimination and Gauss-Siedel iteration methods. Curve fitting- linear and nonlinear regression analysis. Backward, Forward and Central difference relations and their uses in Numerical differentiation and integration, Application of difference relations in the solution of partial differential equations. Numerical solution of ordinary differential equations by Euler, Modified Euler, Runge-Kutta and Predictor-Corrector method.

Computer Programming:

Introduction to computer programming in C and C++ languages. Arithmetic expressions, Simple programs. Concepts of variables, program statements and function calls from the library (printf for example) C data types, int, char, float etc. C expressions, arithmetic operations, relational and logic operations. One dimensional arrays and example of iterative programs using arrays, 2-d arrays. Use in matrix computations. Concept of Sub-programming, functions. Example of functions. Argument passing mainly for the simple variables. Pointers, relationship between arrays and pointers. Argument passing using pointers. Array of pointers, Passing arrays as arguments. Strings and C string library. Structure and unions. Defining C structures, passing structures as arguments.

Modeling Biosystems:

Fundamentals of applying mathematical modeling techniques to physiological systems in order to develop models that may be used to simulate their behavior. Different types of models and their relation with numerical methods that may be used for their solution.
Linear and non-linear biological systems and equations responsible for building the model of such systems. Finite difference methods – ordinary and partial differential equation application in biological system modeling.

Modeling tools and application

Familiarization with programming in MATLAB for building models, Labview for signal processing, and COMSOL for multiphysics coupling applications. A project on practical applications.

Reference Books:

1. Shastry, S.S., "Numerical Methods", Prentice Hall Inc., India, 1998.
2. Noble Ben, "Numerical Methods", New York International Publications, New York, 1964.
3. Grewal, B.S., "Numerical Methods", Khanna Pub., New Delhi, 1998.
4. Kernighan, B. W. and D .M. Ritchie, "The C Programming Language", Prentice Hall of India, 1998.
5. Yashavant P. Kanetkar. Let Us C Fifth Edition, BPB Publications
6. J.T. Ottesen, M.S. Olufsen, and J.K. Larsen. Applied Mathematical Models in Human Physiology
7. Gilat, A., MatLab: An Introduction withApplications, 5th ed, WileyandSons 2014.
8. Van Wijk van Brievingh, R.P., Moeller, D.P.F.: Biomedical Modeling and Simulation on a PC, New York, Springer Verlag, 1993.

Another Lab course for this specialization is "***Sensor and Medical Instruments Lab***" which is common with Biomedical Instrumentation specialization.

Specialization: ***Nanoscience and Nanomaterial***

Paper Name: **NANOSCIENCE AND ITS APPLICATIONS**
Paper Code: **PHY21420**
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 Outcomes:

1. **CO1: Define** key concepts in nanostructured materials, molecular electronics, and nanobiology, including their applications in electronics, photonics, and sensors.

2. **CO2: Explain** the quantum effects and electronic behavior in nanostructures, including single-electron devices, Coulomb blockade, and resonant tunneling phenomena.

3. **CO3: Apply** theoretical models and experimental techniques to analyze nanoscale materials' electronic, photonic, and gas sensing properties.

4. **CO4: Analyze** the role of molecular and nanoscale fluctuations in biological systems and their implications for nanobiology and bio-nanotechnology.

5. **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.

6. **CO6: Design** innovative nanoscale devices and systems, such as molecular electronics, quantum-based lasers, and gas sensors, for advanced technological and scientific applications.

Catalogue Description:

Nanoscience and Its Applications explores how nanoscience is used in modern industry to increase product performance, including an understanding of how these materials and systems, at the molecular level, provide novel properties and physical, chemical, and biological phenomena that have been successfully used in innovative ways in a wide range of industries.

Course Content:

[8 lecture hours]

Nano-structured materials

About size Scales, What is gained by nano-structuring, nanostructures for electronics, zero-dimensional electronic structures: Quantum dots. 2D nanostructures: Super lattices and hetero-structures, Photonic application: 2D photonics for lasers, 3D photonics: band gap materials. Magnetic properties: Super-Paramagnetism, Nano magnetic device: giant magneto resistance.

[12 lecture hours]

Electrons in Nanostructures

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.

[10 lecture hours]

Molecular-Electronics

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.

[8 lecture hours]

Nanobiology

Introduction to molecular biology, some mechanical properties of proteins, powering bio-nano-machines, where biological energy comes from, types of molecular motors, the central role of fluctuations in biology, effect of nano-scale fluctuation in the evolution of the mind.

[5 lecture hours]

Electronic and Photonic Materials

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.

[5 lecture hours]

Gas Sensor Materials

Criteria for the choice of materials, Experimental aspects, material properties, measurement of gas sensing property, sensitivity; Discussion of sensors for various gases, Gas sensors based on semiconductor devices.

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: **NANOMATERIALS AND FABRICATION TECHNOLOGIES**
Paper Code: **PHY21425**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. To introduce the foundational concepts of nano-materials and their unique size-dependent properties.
2. To explore the synthesis of nanomaterials using chemical and physical methods.
3. To provide insights into the fabrication and analysis techniques used in nano-materials, including lithography and self-assembly.
4. To understand the applications and properties of nano-composites and carbon-based nanomaterials.

Course Outcomes:

1. **CO1: Describe** the fundamental concepts of nanomaterials, including their structures, properties, and applications.

2. **CO2: Explain** various chemical and physical methods for synthesizing and fabricating nanomaterials, including their advantages and limitations.

3. **CO3: Apply** concepts of quantum confinement, band-gap variation, and semiconductor device physics to analyze the behavior of nanostructures.

4. **CO4: Analyze** lithographic processes and self-assembly techniques for creating nanoscale materials and devices, considering their precision and efficiency.

5. **CO5: Evaluate** the properties and performance of different types of nanocomposites, such as carbon nanostructures and core-shell composites, for various applications.

6. **CO6: Design** advanced nanomaterials and devices using a combination of chemical synthesis, fabrication techniques, and lithography processes for real-world applications.

Catalogue Description:

The course should give a basic introduction to chemical and physical principles in the synthesis of inorganic nanostructured materials. In addition, basic principles of finite size effects will be covered. The course will also cover different methods for synthesis and characterization of different nanostructures and nanostructured bulk materials. Prerequisites include general knowledge in chemistry, physics and material science.

Course Content:

[5 lecture hours]

Introduction to nano-materials:

Introduction to nano-materials, 1D, 2D and 3D nanostructured materials, Properties of nano-materials; mechanical-physical-chemical properties role of size innano-materials, nanoparticles, semiconducting nanoparticles, nanowires, nano-clusters, quantum wells, conductivity and enhanced catalytic activity compared to the same materials in the macroscopic state.

Semiconductor nanoparticles: size-dependant physical properties, Melting point, solid state phase transformations, Band-gap variations-quantum confinement, and effect of strain on band-gap in epitaxial quantum dots. The *p-n* junction and the bipolar transistor; metal semiconductor and metal-insulator, Semiconductor junctions; field-effect transistors, MOSFETs, CMOS: hetero-structures, high-electron-mobility devices, HEMTs, Quantum Hall effect, Single electron transistors (SETs): quantum dots, single electron effects, Coulomb Blockade.

[10 lecture hours]

Chemical Routes for Synthesis of Nanomaterials:

Chemical Routes for Synthesis of Nanomaterials: Chemical precipitation and coprecipitation; Metal nanocrystals by reduction, Sol-gel synthesis; Micro-emulsions or reverse micelles, myle formation; Solvothermal synthesis; Thermolysis routes, Microwave heating synthesis; Sonochemical synthesis; Electrochemical synthesis; Photochemical synthesis, Synthesis in supercritical fluids

[4 lecture hours]

Self-Assembly and Analysis:

Self-Assembly and analysis: Process of self-assembly, semiconductors islands, monolayers, nature of catalysis, porous materials, pillared clays, colloids.

[5 lecture hours]

Fabrication of Nanomaterials by Physical Methods:

Fabrication of Nanomaterials by Physical Methods: Inert gas condensation, Arc discharge, Plasma arc technique, RF plasma, MW plasma, Ion sputtering, Laser ablation, Laser pyrolysis, Ball Milling, Molecular beam epitaxy, Chemical vapour deposition method and Electro deposition.

[8 lecture hours]

Different Lithography Process:

Photo Lithography:Basic process, Optical lithography, different modes of Optical projection lithography, Multistage scanners, resolution and limits of photolithography, Resolution enhancement techniques, Mask and its application, Photomask, E beam lithography and SEM based nanolithography and nano-manipulation, Ion beam lithography, oxidation and metallization. Deep UV lithography, X-ray based lithography.

[8 lecture hours]

Nano-composites:

Nano-composites: An Introduction: Types of Nano-composite (i.e. metal oxide, ceramic, glass and polymer based); Core-Shell structured nano-composites Super hard Nano-composite: Synthesis, applications and milestones. Carbon Nano Structures: DLCs, Fullerenes, C60, C80 SWNT and MWNT; Properties: Mechanical, Optical and Electrical properties.

Reference Books:

1. Chemistry of nanomaterials: Synthesis, properties and applications by CNR Rao et.al.
2. Nanoparticles: From theory to applications; G. Schmidt, Wiley Weinheim 2004.
3. A Three Beam Approach to TEM Preparation Using In-situ Low Voltage Argon Ion Final Milling in a FIBSEM
4. Thin Film Phenomenon by K.L. Chopra, McGraw-Hill
5. Methods of Experimental Physics (Vol 14) by G.L.Weissler and R.W. Carlson ―Vacuum Physics and Technology‖
6. A User's Guide to vacuum Technology by J.F.O'Hanlon, John Wiley and Sons
7. Evaporation: Nucleation and Growth Kinetics‖ by J.P. Hirth and G.M.Pound, Pergamon Press

Paper Name: **NANOSCALE TRANSPORT PHENOMENA**
Paper Code: **PHY21436**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Equip students with a solid understanding of the properties and classifications of nano-materials, including 1D, 2D, and 3D structures.
2. Introduce various chemical and physical methods for synthesizing nano-materials, enabling students to evaluate their applicability and effectiveness.
3. Analyze the applications of nano-materials in electronics, photonics, and biotechnology, fostering an appreciation for their impact on technology and society.
4. Develop practical skills in designing experiments, measuring properties, and interpreting data related to nano-materials and their behaviors.

Course Outcomes:

1. **CO1: Define** key concepts related to characteristic length scales, quantum confinement, and electron transport in nanostructures.

2. **CO2: Explain** the physical principles underlying models of electron transport, including the Boltzmann Transport Equation, Tight Binding Model, and thermoelectric effects.

3. **CO3: Apply** theoretical techniques such as the Landauer-Büttiker formalism, wave-guide theory, and Green's Function Technique to analyze conductance and quantum transport phenomena.

4. **CO4: Analyze** localization phenomena in disordered systems, quasi-crystals, and other quasi-periodic systems using advanced mathematical models.

5. **CO5: Evaluate** transport properties and quantum interference effects, such as persistent currents and the Aharonov-Bohm effect, in closed quantum systems.

6. **CO6: Design** models and simulations for nanoscale systems using theoretical frameworks like Trace Map techniques, Tight Binding models, and Green's Function methods for real-world applications.

Catalogue Description:

This course explores the foundational concepts of quantum transport and nanoscale systems. It introduces the physics of quantum confinement, mesoscopic observables, and nano-devices. Key topics include electron transport models, conductance calculations using the Landauer-Büttiker formalism, and quantum interference phenomena. The course also delves into advanced concepts like electronic localization in random and quasi-periodic systems. Students will analyze transport properties and conductance in various quantum systems using both theoretical and computational techniques.

Course Content:

[5 lecture hours]

Module 1:

Introduction to the Characteristic Length scales, Mesoscopic observables in nanostructures, Nano-structures and Nano-devices, Quantum confinement, 2D Electron Gas and its properties, Lateral confinement in Quantum Wires and Quantum Dots.

[5 lecture hours]

Module II:

Brief idea of electron transport in macroscopic systems. Free electron model, Nearly Free Model, Tight Binding Model, Boltzmann-Transport Equation, Electrical and Thermal conductivity, Temperature dependence of resistivity, Thermoelectric Effect, Seebeck and Peltier Effect.

[10 lecture hours]

Module III:

Tight Binding Model in discrete Wannier basis. Energy dispersion relation and Eigenstates calculations in various linear systems like 1D ordered chain, alternating chain, Ladder network, 2D square lattice, Graphene, Graphene nano-ribbons (Zigzag and Armchair edge), Kagome Lattice, Lieb Lattice, Fractal Geometries etc. Formation of Edge states.

[10 lecture hours]

Module IV:

Conductance from Transmission, Landauer-Büttiker formalism for open system transport for Two-terminal and Multi-terminal quantum systems, Landauer formula. Calculation of Transmission probability by (i) Wave-guide Theory, (ii) Transfer-Matrix Method, (iii) Green's Function Technique. S matrix and T matrix, Fisher-Lee relation, Calculation of Junction current and Circular current. Application of Landauer formalism in various systems like a magnetic chain, a Quantum ring, etc.

[10 lecture hours]

Module V:

Quantum Transport in Closed systems, Quantum Interference, Aharonov-Bohm Effect, Persistent Current Phenomena, Drude Weight, Magnetic susceptibility, Calculation of persistent current by (i) Derivative Method, (ii) Green's function Technique.

[10 lecture hours]

Module VI:

Electronic Localization, Inverse Participation Ratio, Lyapunov Exponent, Shanon entropy, Electronic localization in Random disordered lattice, Quasi-crystals, Aubry-Andre-Harper Model. Study of energy Eigenstates in various Quasi-periodic systems like Fibonacci lattice (Golden Mean sequence, Silver mean, copper mean etc.), Thue-Morse lattice, Period Doubling chain etc. Trace Map and Anti-Trace map Technique.

Reference Books:

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, ―Nanoelectronics and Nanosystems, Springer (2004).

6. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications by Vladimir.V.Mitin.

Paper Name: **NANOELECTRONICS AND NANOPHOTONICS**
Paper Code: **PHY21441**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

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 Outcomes:

1. **CO1: Recall** fundamental principles of free electron theory, quantum conductance, and materials used in nanoelectronics.

2. **CO2: Explain** the principles of ballistic and diffusive transport, electron transport in semiconductors, and the role of phonon transport in thermal conductivity.

3. **CO3: Apply** theoretical models to analyze electron transport in low-dimensional structures such as quantum wells, wires, and dots, and interpret their behavior numerically.

4. **CO4: Analyze** thermoelectric effects, Hall Effect, and the behavior of smart contacts in nanostructured devices.

5. **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.

6. **CO6: Design** innovative nanoelectronic devices and systems by integrating principles of quantum mechanics, electron transport, and material science.

Catalogue Description:

This course is intended to cover basics of electronics, transistor, band structure models, nanocapacitors, coulomb blockade, single electron transistor and nanophotonics.

Course Content:

[10 lecture hours]

Free Electron Theory and quantum of conductance

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

[10 lecture hours]

Ballistic and Diffusive Transport

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

[8 lecture hours]

Electron transport in semiconductors and nanostructures

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.

[8 lecture hours]

Electrons in traditional low-dimensional structures

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

[8 lecture hours]

Smart Contacts and Phonon Transport

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.

[10 lecture hours]

Spin Valves and Nanostructure devices

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: **COMPUTATIONAL NANOSCIENCE LAB**
Paper Code: **PHY22446**
Credit: **3**
LTP: **0-0-3**

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:

1. **CO1: Identify** key features of Mathematica/Python/Matlab, including built-in functions, constants, and plotting tools for numerical and symbolic computation.

2. **CO2: Explain** mathematical concepts such as differentiation, integration, and linear algebra through computational approaches using Mathematica/Python/Matlab.

3. **CO3: Apply** computational tools to solve advanced problems in quantum mechanics, spin transport, and molecular systems, such as calculating transmission probabilities and plotting resistance.

4. **CO4: Analyze** complex phenomena like quantum interference, spin polarization, and electronic transport by employing methods such as the Green's Function Technique and Transfer Matrix Method.

5. **CO5: Evaluate** computational models for molecular systems, such as calculating the figure of merit and current-voltage characteristics, under specific physical conditions like dephasing.

6. **CO6: Develop** simulations for advanced quantum mechanical phenomena, such as the Quantum Hall Effect and dispersion spectra, using computational platforms.

Catalogue Description:

This course will provide students with the fundamentals of computational problem-solving techniques that are used to understand and predict properties of nanoscale systems. Emphasis will be placed on how to use simulations effectively, intelligently, and cohesively to predict properties that occur at the nanoscale for real systems. The course is designed to present a broad overview of computational nanoscience and is therefore suitable for both experimental and theoretical researchers.

Course Content:

Module 1:

Introduction to Mathematica, Input and output, Exact and Approximate numbers and built-in Constants, built-in Functions, Defining functions, Lists and Matrices, Generating lists, Displaying Tables and Matrices, Displaying Tables and Matrices, Algebraic expressions, Equation solving, Linear Algebra.
Calculus through Mathematica: Differentiation, Integration, Differential Equation.
Two-Dimensional and Three Dimensional Plots, Parametric Plot, Polar Plot, Plot Options.

Module 2:

Solving the following problems using Mathematica/Python/Matlab etc.: (Any Five)

1. Using Wave-Guide theory, calculate the Electron/Spin transmission probability through a quantum wire/ring.

2. Calculate the Spin transmission probability through a Magnetic quantum wire with different orientations of the local magnetic moments by using Transfer Matrix Method.

3. Simulate All Logical Operations by using the idea of Quantum Interference through Green's Function Technique.

4. Plot the Longitudinal and Transverse Resistance of a Two-Dimensional Electron Gas in presence of a strong Magnetic field

5. Plot the Dispersion Spectra for a 1D chain (Periodic, Alternating), 2D ladder, Graphene, Graphene Nano-ribbons (Arm-chair and Zigzag edge) etc.

6. Calculation of Spin Polarization using Spin-Density Formalism.

7. For a given Molecular system, calculate the Figure of Merit.

8. For a Molecular system, calculate the Current-Voltage Characteristics in presence of Dephasing.

9. Simulation of Quantum Hall Effect/ Spin Hall Effect.

Another Lab course for this specialization is "***Material Science Lab***" which is common with Biomedical Instrumentation specialization.

Specialization: ***Quantum Electronics and Photonics***

Paper Name: **STATISTICAL AND QUANTUM OPTICS**
Paper Code: **PHY21449**
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:

1. **CO1: Define** fundamental concepts of probability distributions, coherence, quantum optics, and light-matter interactions in nanoscale systems.

2. **CO2: Explain** the principles of random processes, stationarity, coherence propagation, and quantum correlation functions, including their mathematical frameworks.

3. **CO3: Apply** theoretical models, such as the van Cittert-Zernike theorem, Mandel’s photon counting formula, and Glauber-Sudarshan representation, to analyze optical and quantum systems.

4. **CO4: Analyze** interference laws, coherence functions, and quantum phenomena such as bunching, anti-bunching, and spontaneous emission in advanced optical setups.

5. **CO5: Evaluate** optical and quantum systems, including photonic crystals, surface plasmons, and beam splitters, to optimize their applications in advanced nanophotonics and quantum technologies.

6. **CO6: Design** innovative optical and quantum devices by integrating concepts of coherence, quantum optics, and nano-optical interactions for scientific and technological applications.

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:

[4 lecture hours]

Unit 1

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

[8 lecture hours]

Unit 2

Random processes, correlations, stationarity, Wiener-Khintchine theorem, Linear Response Theory

[5 lecture hours]

Unit 3

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

[4 lecture hours]

Unit 4

Propagation of coherence function, van Cittert Zernike theorem, Michelson stellar interferometer

[4 lecture hours]

Unit 5

Mandel's photon counting formula, Intensity correlations, Hanbury Brown Twiss effect, intensity interferometry

[4 lecture hours]

Unit 6

Speckle statistics and applications

[4 lecture hours]

Unit 7

Quantization of EM fields, number states, vacuum fluctuations

[5 lecture hours]

Unit 8

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

[4 lecture hours]

Unit 9

Quantum correlation functions, normal and time ordering, two photon coherence function and coincidence rate, Spontaneous emission

[4 lecture hours]

Unit 10

Quantum treatment of beam splitter and interferometers

[10 lecture hours]

Unit 11

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, Light in periodic structures: Photonic crystals and resonators, Surface plasmons. 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)

Paper Name: **OPTICAL THIN FILMS TECHNOLOGY**
Paper Code: **PHY21450**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Familiarize students with the principles and applications of electromagnetic wave propagation in various materials.
2. Enhance students' skills in designing and optimizing thin film coatings using various software tools and optimization techniques.
3. Introduce students to vacuum science and the different techniques for achieving various vacuum levels necessary for thin film deposition.
4. Provide hands-on experience in characterizing optical and non-optical properties of thin films using advanced characterization techniques.

Course Outcomes:

1. **CO1: Recall** the principles of electromagnetic wave propagation, Fresnel equations, and the optical properties of materials for thin film applications.

2. **CO2: Explain** the design and optimization of thin film coatings, including merit functions and optimization techniques.

3. **CO3: Apply** vacuum science concepts and high-vacuum techniques to the deposition and production of optical thin films.

4. **CO4: Analyze** thin film properties, such as reflectance, transmittance, and surface morphology, using advanced characterization techniques.

5. **CO5: Evaluate** the performance of thin film coatings for optical and non-optical applications, considering factors like adhesion, hardness, and surface quality.

6. **CO6: Design** innovative thin film optical systems and optimize their deposition techniques for advanced technological applications.

Catalogue Description:

Optical thin films technology gives a fundamental knowledge about propagation of electro-magnetic in stratified dielectric medium, Fresnel equations Optical properties of materials, metals, semiconductors and dielectrics. This course will also explore optimization techniques and different contemporary software packages. Finally different optical thin film techniques and applications will be discussed.

Course Content

[12 lecture hours]

Unit 1

Propagation of electro-magnetic in stratified dielectric medium, Fresnel equations Optical properties of materials, metals, semiconductors and dielectrics, optical glass materials in the visible and near infrared region, IR optical materials, Multilayer thin film optics, Antireflection coatings, Band pass optical filters, edge filters, dichroics.

[12 lecture hours]

Unit 2

Design –Optimization techniques for thin film multilayer, Merit function as applied to thin film coatings. Brief review of different optimization techniques as applied to optical coatings. Case studies for design approaches for different categories of optical coatings. Exposure to thin film software packages.

[12 lecture hours]

Unit 3

Vacuum Science: Viscous, Lamellar and molecular fluid region, Medium, High and Ultra-high vacuum techniques. Mechanical and High vacuum pumps, ultra-high vacuum pumps. High vacuum measurement techniques, principle, calibration and electronics read out

[24 lecture hours]

Unit 4

Thin film technology: Deposition and production of optical thin films: Thin film deposition techniques thermal/electron beam evaporation, RF/DC sputtering, Ion beam sputtering, pulsed laser beam deposition.
In-situ thickness monitoring: Optical and quartz micro-balance techniques monitoring techniques. Architecture of modern-day coating plants
Characterization of optical thin films: Principles of characterization of optical reflectance, transmittance, absorbance and angle resolved scattering. Principles of spectrophotometers and ellipsometers. FTIR spectrometers
Characterization of non-optical properties of thin films: Mechanical adhesion, abrasion and hardness. Surface characterization techniques for thin films: Surface morphology, X-ray structure, Chemical composition. SEM, TEM and AFM instruments for thin film characterization

Reference Books:

1. Thin film optical filters, Angus Macleod
2. Principles of optics, Born and Wolf,
3. SPIE milestone series on -Design of optical coatings

4. Optical Thin films – User hand book – James D Rancourt
SPIE Press – 1996 – ISBN 0819422851
5. Practical Design and Production of Optical Thin Films – Second Edition – Ronald Ron Wiley –CRC Press – 2002 ISBN 0824708490
6. Handbook of Thin Film Technology- Leon –Imaissel and Reihard Glang –Mc Graw –Hill Book Company -1970 –ISBN 0070397422

Paper Name: **GUIDED WAVE OPTICS and ELECTRO OPTICAL SENSING**
Paper Code: **PHY21451**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Understand the fundamental characteristics of optical fiber waveguides and the principles of ray theory.
2. Evaluate the effects of dispersion and fiber losses in optical fibers, including nonlinear optical phenomena.
3. Implement measurement techniques to assess the performance of optical fibers and their components.
4. Examine the design and application of optical fiber amplifiers and integrated circuits.
5. Explore sensor technologies in optical systems, focusing on their applications in spacecraft and remote sensing.

Course Outcomes:

1. **CO1: Define** the fundamental characteristics of optical fiber waveguides, including modes, numerical aperture, and types of fibers.

2. **CO2: Explain** the phenomena of dispersion, nonlinear optical effects, and fiber losses in optical fibers, along with polarization-maintaining fibers.

3. **CO3: Apply** measurement methods to characterize optical fibers, including attenuation, numerical aperture, and birefringence.

4. **CO4: Analyze** coupling mechanisms in optical fibers and design practical solutions for splicing, jointing, and connectorization of optical waveguides.

5. **CO5: Evaluate** the performance of optical fiber amplifiers, sensors, and integrated circuits for advanced communication and sensing applications.

6. **CO6: Design** space craft sensors and imaging systems for applications in Earth observation, cartography, and navigation, including modeling, calibration, and performance analysis.

Catalog Description:

Guided wave optics and electro optical sensing gives a fundamental knowledge about Optical Fiber Waveguides. This course will also explore dispersion in single mode fibers, Fiber losses attenuation coefficient, Nonlinear optical effects, different Measurement Methods in Optical Fibers. Coupled mode theory, optical fiber amplifier and applications will also be covered. Finally different electro-optical sensor, their characteristics, signal processing techniques, Space craft sensors, Star sensors, Imaging sensors etc. will be discussed.

Course Content

[8 lecture hours]

Unit 1

Basic characteristic of Optical Fiber Waveguides – Ray theory- Acceptance angle, Numerical aperture, skew rays - Electromagnetic Modes in Planar waveguides and Cylindrical Waveguides, Goos-Haenchen shift - Step index and Graded index Fibers- Single Mode and multimode fibers

[10 lecture hours]

Unit 2

Dispersion in single mode fibers- dispersion induced limitations- dispersion management, Fiber losses attenuation coefficient, Nonlinear optical effects-SRS, SBS, SPM - modal birefringence and polarization maintaining fibers

[4 lecture hours]

Unit 3

Measurement Methods in Optical Fibers – attenuation, refractive index profile, numerical aperture pulse dispersion and bandwidth, cutoff wavelength, bending loss, mode field diameter birefringence measurements, OTDR

[6 lecture hours]

Unit 4

Coupled mode theory and applications- coupling equations, degenerate and non-degenerate mode coupling, coupling between optical source to waveguide, fiber to fiber joints, fiber splicing, optical fiber connector between waveguides

[4 lecture hours]

Unit 5

Optical Fiber Amplifiers- Optical amplification, Erbium doped Fiber Amplifier, Fiber Raman Amplifier, Wide band amplifiers. Optical integrated circuits.

[10 lecture hours]

Unit 6

Sensor Overview: Photometry and Radiometry, Radiation Sources and characteristics. Detectors- Imaging and non-imaging [Thermal detectors, Photon detectors, Detector arrays: CCDs, CID, FLIR etc.] and their characteristics. Sensor optics, Sensor instrumentation, Signal processing techniques

[18 lecture hours]

Unit 7

Space craft sensors: Optical Attitude Sensors: Fiber Optic gyros [with integrated optics], Ring Laser

Gyros, Star sensors - Space craft attitude determination and control. Line of Sight Sensors- IR Earth sensor, Sun Sensors, Star Sensor andTrackers. Sensors/System for Space craft precision Pointing and navigation.

Imaging sensors: Remote sensing sensors for Earth observation, Cartography Hyper spectral Sensors. Modeling, design, analysis, calibration and Performance evaluation of the above.

Reference Books:

1. Introduction to Fiber Optics, Ghatak and Thyagarajan, Cambridge University Press (2009)
2. Foundations for Guided wave Optics, Chin-Lin Chen, John Wiley and Sons (2007)
3. Optical Fiber Communications, Gerd Keiser, Fourth Edition, Tata McGraw Hill (2008)
4. Optical Fiber communications, J M Senior, Prentice Hall of India (1994)
5. Fundamentals of Optoelectronics, C R Pollock, Irwin Inc., (1995)
6. Fiber Optic communications systems, G P Agrawal, Third Edition, Wiley Interscience (2002)
7. Integrated Optics-Theory and Technology, R G Hunsperger, Sixth edition, Springer (2009)
8. Photonics-Optical Electronics in Modern communications, A Yariv and P Yeh, Sixth edition, Oxford University Press (2007)
9. Essential Macloed Software, By Angus Macleod Fundamentals of Space Systems by Vincent L. Pisacane, Oxford University Press, 2005
10. Spacecraft dynamics and Control: A practical Engineering approach- Marcel J.Sidi, Contributor Michael J.Rycroft, Wei Shyy, Cambridge University Press, 2000,
11. Spacecraft Attitude determination and Control by Computer Sciences, Corporation Attitude Systems operation, James Richrad Wertz, Springer, 1978,
12. Scientific Charge Coupled devices, James R.Janesick, SPIE Press

Paper Name: **LASER and ADVANCED OPTOELECTRONICS**
Paper Code: **PHY21452**
Credit: **4**
LTP: **4-0-0**

Course Objectives:

1. Understand the principles of quantum theory and the conditions necessary for laser action.
2. Analyze the operation of various laser systems, including atomic gas lasers, solid-state lasers, and semiconductor lasers.
3. Explore the applications of lasers in detection, ranging, material processing, and metrology.
4. Examine optoelectronic devices, including their principles and detection methods.

Course Outcomes:

1. **CO1: Recall** the quantum theory of atomic energy levels, radiative and nonradiative decay, laser action conditions, and emission broadening.

2. **CO2: Explain** the principles of laser oscillation, population inversion, rate equations for multi-level systems, and laser cavity modes.

3. **CO3: Apply** concepts of laser beam dynamics, Q-switching, mode locking, and pulse compression to analyze stable resonators and ultra-fast optical pulse generation.

4. **CO4: Analyze** the operational principles and applications of different laser systems, including gas, molecular, plasma, solid-state, and semiconductor lasers.

5. **CO5: Evaluate** laser applications in detection, ranging, material processing, metrology, medical fields, and space technologies, considering their efficiency and societal impact.

6. **CO6: Design** optoelectronic systems using optical radiation detectors, optoelectronic modulators, and advanced laser technologies for innovative applications in science and engineering.

Catalogue Description:

Lasers and their applications have become integral part of our society. Today the laser systems have ubiquitous applications in almost all the areas. This course will develop understanding and experience about the various laser systems and their applications. Laser and advance optoelectronics gives a fundamental knowledge about laser quantum theory, complete over view on conditions for laser action. This course will also explore Laser oscillation, Laser amplifier, population of inversion, resonator. Q-switching and Mode locking, Generation of ultra-fast Optical pulses will also be covered. Finally different type of Lasing system will be discussed. Some contemporary optoelectronics devices are also explored to have advance knowledge.

Course Content:

[5 lecture hours]

Unit 1

Quantum Theory of Atomic Energy Levels – Radiative and Nonradiative decay of excited state atoms –Emission Broadening and linewidth – Radiation and Thermal equilibrium – Conditions for laser action

[4 lecture hours]

Unit 2

Laser Oscillation above threshold - Laser Amplifiers – Requirements for obtaining population inversion – Rate Equations for three and four level systems – Laser pumping requirements – Laser Cavity modes

[4 lecture hours]

Unit 3

Stable resonators – Gaussian beams- Special Laser Cavities – Q-switching and Mode locking – Generation of ultra-fast Optical pulses- Pulse compression

[10 lecture hours]

Unit 4

Atomic Gas Lasers – He-Ne, Argon ion, He-Cd — Molecular Gas Lasers – CO2, Excimer, Nitrogen—X-Ray

Plasma Laser — Free-Electron Laser — Organic Dye lasers — Solid-state lasers – Ruby, Nd:YAG, Alexandrite, Ti:Sapphire, LED, Semiconductor lasers, Heterojunction Lasers, quantum well lasers, VCSEL, DFB and DBR Lasers

[22 lecture hours]

Unit 5

Laser for detection and ranging- LIDAR applications-Doppler wind LIDAR, Differential Absorption LIDAR for water vapor monitoring.

Laser application in material processing – esp. CO2, YAG, Excimer, Ruby lasers - [material processing, Cutting, Welding, drilling, micro machining] – Interaction of laser radiation with matter, Heat Flow Theory, Process characteristics etc.

Laser anemometry, Schlieren Techniques for wind tunnels, Holography etc

Lasers for metrology – Interferometery for surface characterization, precision length measurement, time standards etc, medical applications of lasers

Lasers for space applications – free space communication, laser propulsion, laser ignition, Optical Rotation sensors and their applications for space navigation: Sagnac Interferometers and their applications for space

[15 lecture hours]

Unit 6

LED, Semiconductor lasers, Heterojunction Lasers, quantum well lasers, VCSEL, DFB and DBR Lasers
Detection of Optical radiations – Basic Principle, Thermal detectors, Photo multipliers, photoconductive detectors, Photo diodes, Avalanche photodiodes, CCDs, Image Intensifiers, Arrays, Solar Cells, noise considerations
Optoelectronic Modulators – Basic principle, Birefringence, Optical Activity, EO, AO and MO Effects and modulators

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

Paper Name: **Advanced Photonics Lab I**
Paper Code: **PHY22453**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Understand advanced principles of optics and photonics in experimental setups.
2. Utilize computational tools for modeling and simulating optical phenomena.
3. Design experiments to explore the fundamental properties of lasers and optical fibers.
4. Analyze data to derive insights in optical science.

Course Outcomes:

1. **CO1: Recall** the principles of optical and waveguide theory, refractive index measurement, and thin film synthesis for experimental applications.

2. **CO2: Explain** the theoretical and experimental principles behind Fabry-Perot interferometers, Abbe refractometers, and thin film coating methods.

3. **CO3: Apply** computational and experimental techniques to analyze optical spectra, surface plasmon resonance (SPR) sensors, and crystalline structures of thin films.

4. **CO4: Analyze** the results of experiments involving quantum wire transmission probability, Fourier transforms of optical signals, and metal thin film crystalline structures.

5. **CO5: Evaluate** the efficiency and accuracy of optical sensors, waveguides, and thin films, considering the experimental challenges and design constraints.

6. **CO6: Design and implement** innovative experiments for advanced optical and material analysis using tools like MATLAB and thermal evaporation techniques.

Catalog Description:

Advanced photonics lab I gives a practical knowledge about interferometer and application area. Different simulation methods will be explored to have contemporary knowledge in broad field. Optical fiber-based sensor technology by implementing surface plasmon resonance has been nurtured at its ground level. Optical signal processing technology using MATLAB, FEM etc. will be also explored in this course.

Course Content

Experiment 1

Fabry-Perot interferometer and etalon (finesse with laser)

Experiment 2

Determination of refractive index of various liquids and solids by Abbe Refractometer.

Experiment 3

Using Wave-Guide theory, calculate the Electron/Spin transmission probability through a quantum wire/ring.

Experiment 4

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

Experiment 5

Optical Spectrum analysis using MATLAB

Experiment 6

Analysis of optical signal using Fourier Transform Method

Experiment 7

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.

Paper Name: **Advanced Photonics Lab II**
Paper Code: **PHY22454**
Credit: **3**
LTP: **0-0-3**

Course Objectives:

1. Understand the fundamental principles of laser properties and measurements.
2. Apply optical techniques for analyzing light and materials.
3. Design experiments to measure physical properties using lasers and sensors.
4. Evaluate the performance of photonic devices and sensors through experimentation.

Course Outcomes:

1. **CO1: Recall** the principles of laser optics, light polarization, and optical fiber sensing for experimental applications.
2. **CO2: Explain** the working mechanisms of lasers, photoresistors, solar cells, and optical fiber sensors in various experimental setups.
3. **CO3: Apply** measurement techniques to determine beam divergence, particle size, dielectric constants, and optical properties in different experimental conditions.
4. **CO4: Analyze** the experimental results to evaluate properties like beam divergence, particle size, I-V characteristics, and light polarization.
5. **CO5: Evaluate** the performance of optical devices like solar cells and optical fibers based on experimental data, identifying factors affecting efficiency and sensitivity.
6. **CO6: Design and implement** experiments involving laser holography, optical sensors, and advanced optics techniques, demonstrating precision and innovation.

Catalog Description:

Advanced photonics lab II gives a practical knowledge about laser characteristics and application area. Different optoelectronics devices will be explored to have contemporary knowledge in broad field. Optical fiber-based sensor technology has been nurtured at its ground level.

Course Content

Experiment 1

Determine the peak power and beam divergence of Laser beam.

Experiment 2

Particle size determination by dynamic light scattering.

Experiment 3

Study of Laser holography.

Experiment 4

Measurement of diameter of thin wire and groove spacing of CD by laser beam.

Experiment 5

To analyze elliptically polarized Light by using a Babinet's compensator.

Experiment 6

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

Experiment 7

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

Experiment 8

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

Experiment 9

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

ADDITIONAL COMPULSORY CORE COURSES

Paper Name: **TERM PAPER LEADING TO DISSERTATION**
Paper Code: **PHY25430**
Credit: **4**

Course Objectives:

1. Guide students in selecting relevant research topics in physics.
2. Facilitate the development of research methodologies and literature review skills.
3. Support the formulation of hypotheses and objectives for the dissertation.
4. Encourage critical analysis and synthesis of scientific literature.

Course Outcomes:

1. **CO1: Recall and articulate** foundational concepts and recent developments in the chosen research area.

2. **CO2: Explain** the context, relevance, and objectives of the term paper topic through a review of existing literature.

3. **CO3: Apply** appropriate research methodologies and tools to perform a detailed study or analysis related to the term paper topic.

4. **CO4: Analyze** data, theoretical frameworks, or experimental results to derive meaningful insights and identify gaps for future research.

5. **CO5: Evaluate** the significance, limitations, and potential impact of the findings in the context of the chosen research area.

6. **CO6: Develop** a well-structured term paper that lays the groundwork for the dissertation, including clear objectives, methodologies, and proposed future work.

Catalogue Description:

This course guides students in selecting relevant research topics, conducting literature reviews, and formulating hypotheses as they prepare for their dissertation work. Students will develop skills in critical analysis, research methodology, and effective communication of scientific ideas.

Paper Name: **INTERNSHIP**
Paper Code: **PHY24431**
Credit: **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:

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

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

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

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

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

6. **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: **SEMINAR ON CONTEMPORARY RESEARCH IN PHYSICS and APPLIED PHYSICS**

Paper Code: **PHY25447**

Credit: **3**

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:

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

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

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

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

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

6. **CO6: Prepare and deliver** well-structured presentations or reports on contemporary research topics, demonstrating effective communication and scientific rigor.

Catalogue Description:

In this course unit, students will get introduced to some contemporary fields of physics and applied physics topics. 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: **PHY25448**
Credit: **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.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
PHY21401												
CO1	3	2	1	1	0	0	0	0	1	0	1	1
CO2	3	2	1	1	1	0	0	0	1	1	1	1
CO3	3	3	2	2	2	0	0	0	1	2	1	1
CO4	3	3	2	2	2	1	0	0	2	2	2	1
CO5	3	3	2	2	2	1	0	0	2	1	2	1
CO6	3	2	1	1	2	2	0	0	0	2	1	1
PHY21402												
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CO3	3	3	2	2	2	0	0	0	0	2	1	0
CO4	3	3	2	2	2	1	0	0	2	1	1	1
CO5	3	3	2	1	2	1	0	0	1	1	1	1
CO6	3	2	1	0	3	2	1	0	0	2	1	0
PHY21403												
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CO5	3	3	2	1	2	1	0	0	0	1	1	1
CO6	3	2	1	0	3	2	1	0	0	2	1	0
PHY21404												
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CO3	3	3	2	2	2	0	0	0	0	2	1	0
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CO5	3	2	1	0	3	2	1	0	0	2	1	1
CO6	3	3	2	0	2	1	0	1	0	2	1	1
PHY21460												
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CO3	3	2	3	2	1	0	0	0	0	2	1	0
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CO5	3	3	2	1	3	1	0	0	0	1	0	1
CO6	3	2	3	1	2	2	0	0	0	1	1	0
PHY22405												
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CO3	3	3	2	2	1	0	0	0	1	2	0	0
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CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY22406												
CO1	3	2	1	0	1	0	0	0	1	0	1	0
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CO3	3	3	2	2	1	0	0	0	1	2	0	0
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CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY21407												
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CO3	3	2	2	1	2	0	0	0	0	2	1	0
CO4	3	3	2	1	2	1	0	0	1	1	0	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	3	2	0	2	3	1	0	0	2	1	0
PHY21408												
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CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	0	2	3	1	0	0	2	1	0
PHY21409												
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CO3	3	2	2	1	2	0	0	0	1	1	1	0
CO4	3	2	2	1	2	1	0	0	0	2	1	0
CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21410												
CO1	3	2	1	0	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	1
CO3	3	2	2	1	1	0	0	0	1	2	1	0
CO4	3	3	2	1	2	1	0	0	0	1	0	1

CO5	3	2	1	1	3	2	0	0	0	1	1	0
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY22461												
CO1	3	2	3	0	1	0	0	0	1	0	1	0
CO2	3	2	2	1	1	0	0	0	0	1	1	0
CO3	3	3	2	1	2	0	0	0	0	2	0	1
CO4	3	2	2	2	2	1	0	0	0	1	1	0
CO5	3	3	2	0	3	2	0	0	0	1	0	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY22411												
CO1	3	2	1	0	1	0	0	0	1	0	1	0
CO2	3	3	2	0	2	0	0	0	0	1	1	1
CO3	3	3	2	2	1	0	0	0	1	1	1	0
CO4	3	2	2	1	2	1	0	0	0	2	1	0
CO5	3	3	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY22413												
CO1	3	2	3	0	1	0	0	0	1	0	1	0
CO2	3	3	2	0	2	0	0	0	0	1	1	0
CO3	3	2	3	2	1	0	0	0	1	2	0	1
CO4	3	2	2	1	2	1	0	0	0	2	1	0
CO5	3	3	2	0	3	2	0	0	0	1	0	1
CO6	3	2	3	1	2	3	1	0	0	2	1	1
PHY21414												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	1	0	0	0	1	2	0	1
CO4	3	3	2	1	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21415												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	1	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	1	0
CO4	3	3	2	1	2	1	0	0	0	1	0	1
CO5	3	2	1	1	3	2	0	0	0	1	1	0
CO6	3	2	2	0	3	2	1	0	0	1	1	0
PHY21412												

CO1	3	2	1	0	0	1	0	0	1	0	1	0
CO2	3	3	0	1	0	0	0	0	0	1	1	1
CO3	2	3	2	1	1	0	0	0	1	2	1	0
CO4	2	2	3	2	2	0	0	0	0	1	1	1
CO5	3	2	1	0	3	2	0	0	0	1	1	1
CO6	3	2	2	1	1	3	2	0	0	2	1	1
PHY21416												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	0	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	1	0	1
CO4	3	3	1	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21421												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	1	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY21432												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	1	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21437												
CO1	3	2	1	0	0	0	0	0	1	0	1	0
CO2	3	3	1	0	1	0	0	0	0	1	1	0
CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	3	2	2	2	2	1	0	0	0	1	1	0
CO5	3	3	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY22427												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	1	0	0	0	1	2	0	1

CO4	3	2	2	2	2	1	0	0	0	1	1	0
CO5	3	3	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	2	1	0	0	2	0	1
PHY22442												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	1	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	1	2	3	1	1	0	2	1	1
PHY21418												
CO1	3	2	1	0	0	0	0	0	1	0	1	0
CO2	3	3	0	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	1	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21434												
CO1	3	2	1	0	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1
PHY21423												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	2	1	0	0	1	1	1
PHY21439												
CO1	3	2	1	0	0	0	0	0	1	0	1	0
CO2	3	3	0	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	1	0	0	2	1	1

PHY22429												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	0	1	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	0	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY22444												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	1	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	1	1	0	0	0	1	1	1
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	0	0	2	0	1
PHY21417												
CO1	3	2	1	0	1	0	0	0	1	0	1	0
CO2	3	3	0	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	3	3	2	2	2	1	0	0	0	1	1	0
CO5	3	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	0	0	2	1	1
PHY21422												
CO1	3	2	1	1	0	0	0	0	0	1	1	0
CO2	3	3	1	0	2	0	0	0	0	0	1	0
CO3	2	3	2	1	1	0	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1
CO6	2	2	2	1	2	3	1	1	0	2	1	1
PHY21433												
CO1	3	3	0	1	0	0	0	0	1	0	1	0
CO2	3	2	1	0	2	0	0	0	0	1	1	0
CO3	2	3	2	1	1	0	0	0	1	2	0	1
CO4	2	2	3	2	2	1	0	0	0	1	1	0
CO5	2	2	1	2	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	1	0	2	1	1
PHY21438												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0

CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	2	3	2	2	1	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	1	0	2	0	1
PHY22428												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	2	3	3	1	2	1	0	0	1	2	0	1
CO4	2	2	2	2	2	2	0	0	0	1	1	0
CO5	2	3	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	0	2	3	0	1	0	2	1	1
PHY22443												
CO1	3	2	1	0	0	0	0	0	1	0	1	0
CO2	3	3	0	1	2	0	0	0	0	1	1	0
CO3	2	3	3	1	2	0	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	1	0	2	1	1
PHY21419												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	0	0	2	0	0	0	0	1	1	0
CO3	2	3	1	1	2	0	0	0	1	2	0	1
CO4	2	2	2	2	1	1	0	0	0	1	1	0
CO5	2	2	0	1	3	2	0	0	0	1	1	1
CO6	3	2	2	1	2	3	1	1	0	2	1	1
PHY21424												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	2	1	2	0	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1
CO6	3	2	3	0	2	1	1	1	0	2	1	1
PHY21435												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	2	3	2	1	2	0	0	0	1	2	0	1
CO4	2	2	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1

CO6	3	1	3	2	2	2	1	1	1	2	1	0
PHY21440												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	1	0	0	1	2	0	1
CO4	2	3	2	2	2	2	0	0	0	1	1	0
CO5	2	2	1	1	3	3	1	1	0	1	1	1
CO6	3	2	3	2	2	2	0	0	0	2	1	1
PHY22445												
CO1	3	2	1	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	0	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	0	0	0	1	1	1
CO6	3	0	3	1	2	2	1	0	0	2	0	0
PHY21420												
CO1	3	2	0	1	0	1	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	2	3	3	1	2	1	0	0	1	2	0	1
CO4	2	2	2	2	2	2	0	0	0	1	1	0
CO5	2	2	1	1	3	3	0	0	0	1	1	1
CO6	3	1	3	1	1	2	1	1	0	2	1	1
PHY21425												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	1	0	0	1	2	0	1
CO4	2	3	2	2	2	2	0	0	0	1	1	0
CO5	2	2	1	1	3	3	0	0	0	1	1	1
CO6	3	2	3	2	2	3	1	0	0	2	0	1
PHY21436												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	1	0	0	1	2	0	1
CO4	2	3	2	2	2	2	0	0	0	1	1	0
CO5	2	2	1	1	3	3	0	0	0	1	1	1
CO6	3	1	2	2	2	2	1	0	0	2	1	1
PHY21441												
CO1	3	2	0	1	0	0	0	0	1	0	1	0

CO2	3	3	1	0	2	0	0	0	0	1	0	0
CO3	2	3	3	1	1	1	0	0	0	2	0	1
CO4	1	2	2	2	2	1	0	0	0	1	1	0
CO5	2	1	0	1	3	2	1	0	0	1	1	1
CO6	3	0	3	1	0	2	1	0	0	2	0	0
PHY22446												
CO1	3	2	2	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	1	0
CO3	3	2	3	1	2	1	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	1	0	0	1	1	1
CO6	3	0	3	2	0	3	1	0	0	2	0	0
PHY21449												
CO1	3	2	0	1	0	0	0	0	1	0	1	0
CO2	3	3	1	0	2	0	0	0	0	1	0	0
CO3	3	2	3	1	2	1	0	0	1	2	0	1
CO4	2	3	2	2	2	1	0	0	0	1	1	0
CO5	2	2	1	1	3	2	1	0	0	1	1	1
CO6	3	0	3	2	0	3	1	1	0	2	0	0
PHY21450												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	1	2	0	0	0	0	1	0	0
CO3	2	3	3	2	2	1	0	0	1	2	0	1
CO4	2	2	2	3	2	2	0	0	0	1	1	0
CO5	2	1	0	1	3	2	1	0	0	1	1	1
CO6	3	0	3	2	0	2	1	1	0	2	1	0
PHY21451												
CO1	3	2	1	1	0	0	0	0	1	0	1	0
CO2	3	3	0	1	2	0	0	0	0	1	1	0
CO3	2	3	2	2	2	1	0	0	0	1	0	1
CO4	2	2	2	3	1	1	0	0	0	1	1	0
CO5	2	1	1	1	3	2	1	0	0	1	1	1
CO6	3	0	3	1	0	3	1	1	1	2	1	1
PHY21452												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	3	1	1	2	0	0	0	0	1	0	0
CO3	3	2	3	2	2	1	0	0	1	2	0	1
CO4	2	3	2	3	2	2	0	0	0	1	1	0

CO5	2	1	0	1	3	2	1	1	0	1	1	1
CO6	3	0	2	1	0	2	1	1	0	2	1	1
PHY22453												
CO1	3	2	0	1	0	1	0	0	1	0	1	0
CO2	3	3	1	0	2	1	0	0	0	1	0	0
CO3	3	2	3	2	2	1	0	0	1	2	0	1
CO4	2	3	2	3	2	1	0	0	0	1	1	0
CO5	2	1	0	2	3	2	1	0	0	1	1	1
CO6	3	0	3	1	0	3	1	1	0	2	1	0
PHY22454												
CO1	3	2	1	1	0	0	0	0	1	0	1	0
CO2	3	3	0	1	2	0	0	0	0	1	0	0
CO3	2	3	2	2	2	1	0	0	1	1	0	1
CO4	2	2	2	3	2	1	0	0	0	1	1	0
CO5	1	1	0	1	3	2	1	0	0	1	1	1
CO6	3	0	3	2	0	2	1	1	1	1	1	0
PHY25430												
CO1	3	2	0	1	1	0	0	0	1	0	1	0
CO2	3	2	0	1	2	0	0	0	0	1	1	0
CO3	2	3	2	1	2	1	0	0	0	2	0	1
CO4	2	2	2	2	2	1	0	0	0	1	1	0
CO5	1	1	0	1	3	2	1	0	0	1	1	1
CO6	3	0	2	1	1	2	1	0	0	2	1	3
PHY24431												
CO1	3	1	0	1	2	0	0	0	1	0	1	0
CO2	3	2	1	1	2	0	0	0	0	1	1	0
CO3	2	3	3	1	2	1	0	0	0	1	0	1
CO4	2	2	2	2	2	1	0	0	0	1	1	0
CO5	1	1	0	1	3	2	2	1	0	1	1	1
CO6	3	0	2	1	1	2	1	0	0	2	1	3
PHY25447												
CO1	3	2	0	1	0	1	0	0	1	0	1	0
CO2	3	3	1	1	2	0	0	0	0	1	1	0
CO3	2	3	2	2	2	1	0	0	1	1	0	1
CO4	2	2	2	3	2	2	0	0	0	1	1	0
CO5	1	1	0	1	3	2	2	1	0	1	1	1
CO6	3	0	2	1	1	2	1	1	0	2	1	3
PHY25448												

CO1	3	1	0	1	2	1	0	0	1	0	1	0
CO2	3	2	0	1	2	1	0	0	0	1	1	0
CO3	2	3	3	2	2	2	0	0	1	1	0	1
CO4	2	2	2	3	2	2	0	0	0	1	1	0
CO5	1	1	0	1	3	2	2	1	0	1	1	1
CO6	3	0	2	1	1	2	1	0	0	2	1	3

PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
2.77	**2.32**	**1.78**	**1.30**	**2.00**	**1.80**	**1.06**	**1.0**	**1.03**	**1.37**	**1.00**	**1.05**