MADHABDEV UNIVERSITY

DEPARTMENT OF PHYSICS

SYLLABUS: TWO YEAR AND ONE YEAR M.SC. IN PHYSICS

Under National Education Policy - NEP 2020

Approved in the meeting of the Board of Studies of the Department of Physics on: July 11, 2026

PG SYLLABUS (UNDER NEP-2020) OF THE DEPARTMENT OF PHYSICS MADHABDEV UNIVERSITY

Approved in the meeting of the Board of Studies of the Department of Physics held on July 11, 2026

Members Present

Sl. no.	Name of the member
1.	**Dr. Limpon Bora** Academic Registrar, Madhabdev University
2.	**Dr. Arindam Phukan** (HoD i/c) Chairperson Dept. of Physics, Madhabdev University
3.	**Dr. Lakhinath Borah** Member, Dept. of Physics, Madhabdev University
4.	**Dr. Sudipta Hazarika** Member, Dept. of Physics, Madhabdev University
5.	**Dr. Dhruba Jyoti Gogoi** Member, Dept. of Physics, Madhabdev University
6.	**Prof. Mrinal Kumar Das** External member HoD, Dept. of Physics, Tezpur University
7.	**Prof. Upamanyu Das** External member Dept. of Physics, Bhattadev University

Comprehensive Program Learning Outcomes and Academic Framework
Two-Year and One-Year M.Sc. Physics (Madhabdev University)

Preamble and Institutional Context

The Department of Physics at Madhabdev University has meticulously architected its Master of Science (M.Sc.) curriculum to align seamlessly with the transformative mandates of the National Education Policy (NEP-2020). This academic framework represents a definitive epistemological shift in higher scientific education. Moving away from traditional, rote-based pedagogical models, this curriculum establishes a dynamic, research-intensive, and highly interdisciplinary environment.

The structural design accommodates both the Two-Year M.Sc. (for students entering with a standard three-year bachelor's degree) and the One-Year M.Sc. (for students entering with a four-year FYUGP Honours with Research degree). The primary institutional objective is to cultivate a cohort of physicists who possess profound theoretical depth, rigorous mathematical fluency, advanced computational capabilities, and unwavering ethical standards. By synthesizing classical mechanics, advanced quantum field theories, frontier astrophysical observations, and robust experimental methodologies, the program ensures graduates are fully equipped to address fundamental scientific inquiries and applied technological challenges on a global scale.

Programme Analysis and Strategic Imperative

The conceptualization of this syllabus is rooted in a comprehensive analysis of the contemporary educational landscape and the evolving demands of both academia and the high-technology industry. Traditional physics curricula have often treated theoretical formulations, experimental practice, and computational modeling as isolated silos. This program deconstructs those barriers, recognizing that modern scientific breakthroughs occur at the intersection of disciplines.

Bridging the Theoretical-Applied Divide:

The academic framework is deliberately designed to bridge the gap between abstract theoretical physics and tangible applied technologies. While the core courses instill absolute rigor in mathematical physics, quantum mechanics, and electrodynamics, the Discipline Specific Electives (DSEs) and laboratory modules mandate the practical application of these theories. For instance, theoretical knowledge of solid-state physics is directly coupled with the synthesis of nanomaterials, thin-film characterization, and the design of semiconductor devices.

Research as Pedagogy:

A critical analysis of previous higher education models reveals a delayed introduction to independent research. The Madhabdev University framework corrects this by embedding continuous Research Projects (RP-I through RP-IV) directly into the semester structure. This transitions the student from a passive consumer of textbook knowledge into an active producer of novel scientific literature, ensuring that they experience the iterative, often failure-prone reality of genuine scientific investigation before graduation.

Scope and Professional Trajectories

The scope of this M.Sc. program extends far beyond the traditional pipeline of creating academic lecturers. The curriculum is engineered to produce highly versatile analytical thinkers capable of integrating into diverse, high-value sectors of the modern economy.

1. Premier Academic Research and Doctoral Studies:

The program's rigorous alignment with the syllabi of national-level competitive examinations (CSIR-NET, GATE, JEST) ensures that graduates are immediately competitive for fully funded Ph.D. positions and research fellowships at premier institutes (e.g., IITs, IISERs, TIFR, BARC). The deep theoretical coverage of General Relativity, Quantum Field Theory, and Statistical Mechanics prepares students for cutting-edge research in fundamental physics.

2. Advanced R&D and High-Technology Industries:
The extensive training in applied physics, specifically in analog/digital electronics, microprocessor programming (8085/8051), FPGA architectures, and MEMS technology, positions graduates for lucrative careers in the semiconductor industry, telecommunications, and industrial automation. The focus on instrumentation and data acquisition systems ensures readiness for roles as instrumentation engineers or R&D scientists in commercial laboratories.
3. Space Science, Meteorology, and Environmental Data Analysis:
By integrating dedicated modules on Astronomy, Space Science, and Atmospheric Physics, the program opens pathways to organizations such as ISRO, the Indian Meteorological Department (IMD), and environmental monitoring agencies. Training in climate dynamics and atmospheric modeling equips graduates to participate in critical global sustainability and climate change mitigation efforts.
4. Data Science and Computational Modeling:
Modern physics is inextricably linked to computation. The curriculum's mandate on computational physics—requiring proficiency in Python, numerical ODE solvers (like Runge-Kutta), Monte Carlo simulations, and Machine Learning algorithms (CNNs, LSTMs)—ensures that graduates can seamlessly pivot into high-demand roles in data science, quantitative finance, and artificial intelligence, where complex time-series analysis and mathematical modeling are paramount.

Structural Alignment with the National Education Policy (NEP-2020)

The syllabus operationalizes the foundational philosophies of the NEP-2020 through specific, verifiable structural implementations.
Multidisciplinary Synthesis:
The program rejects the notion of physics as a closed system. Graduates are trained to apply the fundamental laws of physics to allied scientific domains. The curriculum encourages the synthesis of knowledge from chemistry (materials science), mathematics (topology and group theory), computer science (AI and embedded systems), and environmental science (climate dynamics), fostering a holistic understanding of the natural world.
Integration of Indian Knowledge Systems (IKS):
A highly progressive feature of this syllabus is the formal integration of Indian Knowledge Systems, aimed at decolonizing the scientific narrative. Graduates will critically evaluate the historical epistemologies of ancient scholars, from Maharishi Kanada's early atomistic models to the mathematical innovations of the Kerala School. They will trace this intellectual lineage to the 20th-century monumental contributions of Indian physicists like S.N. Bose, C.V. Raman, and Meghnad Saha, recognizing that scientific discovery is a historically continuous and globally shared endeavor.
Credit Mobility and Multiple Entry/Exit:
The program supports the NEP-2020 mandate for flexibility. The one-year M.Sc. option allows students who have already completed a rigorous four-year research-based undergraduate degree to directly specialize and finalize their master's qualifications without redundant coursework.

Comprehensive Program Learning Outcomes (PLOs)

Upon successful completion of the M.Sc. Physics program (One-Year or Two-Year), graduates will demonstrate mastery across cognitive, psychomotor, and affective domains, encapsulated in the following Program Learning Outcomes:
PLO 1: Advanced Disciplinary Knowledge
Graduates will demonstrate an exhaustive, systematic, and critically engaged understanding of the fundamental principles of physical laws, encompassing classical mechanics, quantum theory, electrodynamics, and statistical thermodynamics, extending to specialized frontiers such as cosmology, high-energy particle physics, and condensed matter physics.

PLO 2: Analytical Reasoning and Problem Solving
Graduates will exhibit the ability to deconstruct complex, multifaceted physical phenomena, formulating abstract mathematical models using tensor calculus, differential geometry, and group theory. They will isolate critical variables, apply appropriate theoretical frameworks, and execute precise analytical or numerical solutions.

PLO 3: Methodological Rigor and Experimental Autonomy
Graduates will possess the capability to design, execute, and troubleshoot sophisticated experimental investigations autonomously. They will demonstrate proficiency in operating high-vacuum systems, advanced transducers, and spectroscopic instrumentation, alongside the ability to interface hardware with digital data acquisition (DAQ) systems.

PLO 4: Computational Fluency and Simulation
Graduates will translate physical problems into computational algorithms. They will demonstrate proficiency in programming languages (C, Python) to execute numerical differentiation, integration, and the simulation of quantum and classical multi-particle systems, extending to the deployment of Machine Learning models for time-series physical datasets.

PLO 5: Advanced Statistical Inference and Error Mitigation
Moving beyond standard deviations, graduates will treat physical measurements with rigorous statistical scrutiny. They will execute Maximum Likelihood Estimations (MLE), Bayesian inference, and Monte Carlo uncertainty modeling, validating experimental datasets through formal hypothesis testing (Chi-square, t-tests).

PLO 6: Scientific Communication and Authorship Integrity
Graduates will communicate complex scientific concepts with absolute professionalism. They will demonstrate proficiency in the LaTeX typesetting ecosystem to produce publication-ready manuscripts, encompassing complex mathematical environments and citation management, suitable for peer-reviewed international journals.

PLO 7: Ethical Conduct and Data Stewardship
Graduates will internalize the ethical frameworks of modern scientific research. They will strictly adhere to policies regarding Fabrication, Falsification, and Plagiarism (FFP), navigate authorship taxonomies (CRediT), champion the FAIR data principles (Findable, Accessible, Interoperable, Reusable), and ethically utilize Artificial Intelligence tools in academic writing.

PLO 8: Environmental Awareness and Sustainability
Graduates will apply thermodynamic laws and radiative transfer equations to model atmospheric stability, stratospheric chemistry, and anthropogenic climate forcing. They will critically evaluate IPCC-aligned mitigation strategies, embedding environmental stewardship and global sustainability into their scientific worldview.

PLO 9: Heritage and Historical Contextualization
Graduates will contextualize modern physics within the broader historical narrative, explicitly recognizing and evaluating the contributions of ancient and modern Indian Knowledge Systems (IKS) to the global evolution of mathematics and physical sciences.

PLO 10: Capacity for Lifelong Learning and Adaptability
Graduates will demonstrate the intellectual resilience and cognitive flexibility required to continuously assimilate new scientific paradigms, technological advancements, and interdisciplinary methodologies throughout their professional careers.

Thematic Course Outcomes (COs) Mapping

The curriculum is structured into cohesive thematic clusters, each driving specific, measurable Course Outcomes.

Cluster 1: Mathematical and Theoretical Foundations

(Mathematical Physics, Classical Mechanics, Statistical Mechanics)

- CO 1.1: Construct solutions for inhomogeneous partial differential equations using Green's functions and evaluate linear integral equations.
- CO 1.2: Classify physical symmetries using discrete group representations, continuous Lie groups, and formulate geometric laws using covariant/contravariant tensor calculus.
- CO 1.3: Apply variational calculus to formulate Lagrangian and Hamiltonian dynamics, evaluating phase space via canonical transformations and the Hamilton-Jacobi equation.
- CO 1.4: Derive thermodynamic properties from statistical ensembles, analyzing phase transitions, the Ising model, and the behavior of degenerate quantum gases (Bose-Einstein and Fermi-Dirac statistics).

Cluster 2: Quantum and Subatomic Physics

(Quantum Mechanics II & III, Atomic & Molecular Physics, Nuclear & Particle Physics)

- CO 2.1: Utilize Dirac bra-ket notation, projection operators, and angular momentum algebra to analyze abstract quantum states and systems of identical particles.
- CO 2.2: Evaluate transition probabilities and energy shifts using time-independent perturbation theory, the WKB approximation, and Fermi's Golden Rule.
- CO 2.3: Analyze relativistic wave equations (Klein-Gordon, Dirac) and formulate many-body problems using the formalism of second quantization.
- CO 2.4: Evaluate nuclear structure through the extreme single-particle shell and collective models, and formulate scattering cross-sections using partial wave analysis and the Breit-Wigner resonance formula.

Cluster 3: Electrodynamics and Plasma Physics

(Electromagnetic Theory, Plasma Physics)

- CO 3.1: Apply Maxwell's equations to describe the propagation of electromagnetic waves across bounded, unbounded, and anisotropic media, deriving reflection and transmission coefficients.
- CO 3.2: Analyze the state of light polarization and solve boundary value problems utilizing Lorentz and Coulomb gauge transformations.
- CO 3.3: Analyze the motion of charged particles in non-uniform electric and magnetic fields, evaluating particle confinement mechanisms like magnetic mirrors.
- CO 3.4: Formulate the kinetic theory of plasmas using the Vlasov equation and Magnetohydrodynamics (MHD), evaluating wave propagation and collisionless Landau damping.

Cluster 4: Astrophysics and Atmospheric Sciences

(Astronomy, Space Science, Atmospheric Physics, General Relativity)

- CO 4.1: Plot and interpret stellar evolution via the Hertzsprung-Russell diagram, analyzing solar dynamics and the impact of space weather on planetary environments.
- CO 4.2: Formulate Einstein’s field equations from the action principle and deconstruct the Schwarzschild and Kerr metrics to characterize singularities, event horizons, and black hole thermodynamics.
- CO 4.3: Interpret the dynamics of the Lambda-CDM cosmological model, including the thermal history of the universe, Dark Matter, and Dark Energy.
- CO 4.4: Apply radiative transfer equations and atmospheric thermodynamics to model cloud microphysics, stratospheric ozone depletion, and anthropogenic climate change scenarios.

Cluster 5: Condensed Matter and Applied Electronics

(Solid State Physics, Electronics II, DSE: Electronic/Instrumentation Systems)

- CO 5.1: Deconstruct crystal lattices and Brillouin zones, applying the Kronig-Penney model to evaluate the electronic, dielectric, and magnetic properties of solids.
- CO 5.2: Design and analyze operational amplifier circuits, timing circuits, feedback mechanisms, and sinusoidal oscillators using the Barkhausen criterion.

- CO 5.3: Program 8085/8051 microprocessors using Assembly Language for arithmetic and hardware control tasks, and evaluate modern FPGA and VLSI architectures.
- CO 5.4: Design signal conditioning circuits for biometric sensors, integrate IoT telemetry protocols (MQTT), and characterize smart materials and MEMS devices.

Graduate Attributes (GAs)

Graduate Attributes define the core competencies, defining characteristics, and intrinsic qualities a student will internalize by the time they complete the Two-Year or One-Year M.Sc. program.

- **GA 1: Disciplinary Knowledge & Theoretical Rigor:** Deep, systematic comprehension of fundamental and advanced physical laws—from classical dynamics and quantum field theories to general relativity and condensed matter—enabling the mathematical formulation of complex natural phenomena.
- **GA 2: Analytical & Computational Fluency:** The capability to deconstruct physical systems using advanced mathematics (tensors, group theory) and numerical computation (Python, MATLAB, Runge-Kutta solvers), transitioning seamlessly between theoretical models and algorithmic simulations.
- **GA 3: Experimental Autonomy & Methodological Precision:** Independent proficiency in designing experiments, operating high-end analytical instrumentation (vacuum systems, spectrometers, sensors), and applying rigorous statistical inference (Monte Carlo, Maximum Likelihood Estimation) to physical data.
- **GA 4: Modern Tool Usage:** Adept handling of contemporary hardware and software tools, encompassing microprocessors, FPGAs, Machine Learning models for time-series analysis, and IoT data telemetry protocols.
- **GA 5: Scientific Authorship & Communication:** The ability to articulate complex scientific findings with absolute clarity to both expert and lay audiences, utilizing professional typesetting (LaTeX) to produce publication-ready manuscripts and deliver rigorous academic defenses.
- **GA 6: Professional Ethics & Research Integrity:** Unyielding adherence to scientific ethics, understanding the gravity of research misconduct (FFP), intellectual property rights, FAIR data principles, and the responsible disclosure of AI utilization in research.
- **GA 7: Environmental Stewardship:** A critical understanding of atmospheric physics, climate dynamics, and radiative transfer, equipping the graduate to engage with global sustainability challenges and IPCC-aligned mitigation strategies.
- **GA 8: Cultural Contextualization (IKS):** An appreciation for the historical continuity of science, specifically the epistemological contributions of Indian Knowledge Systems (IKS), fostering intellectual confidence and a decolonized perspective on scientific discovery.
- **GA 9: Lifelong Learning & Adaptability:** The cognitive flexibility to continuously assimilate emerging physical paradigms, adapt to evolving technologies, and engage in autonomous, self-directed learning in a rapidly changing global landscape.

Programme Educational Objectives (PEOs)

Programme Educational Objectives define the professional and career accomplishments that the graduates are expected to achieve within three to five years after completing the program.

- **PEO 1 (Academic Excellence & Frontier Research):** Secure placements in premier doctoral programs or research fellowships by leveraging success in national-level competitive examinations (CSIR-NET, GATE, JEST), subsequently contributing to cutting-edge global research in theoretical, experimental, or astrophysical domains.
- **PEO 2 (Technological & Industrial Leadership):** Apply advanced principles of electronics, solid-state physics, and computational modeling to solve complex, real-world engineering problems

in high-technology sectors such as semiconductor design, telecommunications, automation, aerospace, and data science.
- **PEO 3 (Professional Integrity & Ethical Stewardship):** Exhibit leadership and unyielding ethical integrity in professional environments, championing transparent data practices, rigorous peer-review standards, and the responsible implementation of emerging technologies like AI/ML.
- **PEO 4 (Societal Impact & Sustainable Solutions):** Utilize expertise in atmospheric physics, climate dynamics, and advanced sensor technology to analyze environmental data, contributing meaningfully to climate resilience frameworks, sustainable development goals (SDGs), and public science policy.
- **PEO 5 (Continuous Professional Evolution):** Demonstrate adaptability and sustained professional growth by mastering new theoretical frameworks, computational languages, and interdisciplinary methodologies, drawing continuous inspiration from both global advancements and indigenous scientific heritage.

Research Methodology and Ethical Framework

The syllabus treats research not as a byproduct of education, but as the core pedagogical mechanism. The mandatory course on "Research Methodology in Physics" establishes a rigorous baseline for how science is conducted, recorded, and published.

Data Acquisition and Signal Processing:
Students are trained in the physical limits of measurement systems. They learn to analyze noise spectral densities (Johnson, shot, 1/f) and apply phase-sensitive detection (lock-in amplifiers) to extract weak signals from high-noise environments. This ensures that experimental data collected in subsequent research projects is robust and credible.

Instrumental Mastery:
Rather than treating laboratory equipment as "black boxes," students must deconstruct the operational block diagrams and underlying physics of premier analytical instruments, including UV-Vis spectrophotometers, X-Ray Diffraction (XRD) systems, and Electron Microscopes (SEM/TEM). This includes mastering high-vacuum technology and transducer calibration.

The Ethics of Scientific Authorship:
To participate honorably in the global scientific community, students receive explicit instruction on research ethics. The curriculum covers the severe consequences of Fabrication, Falsification, and Plagiarism (FFP). Students learn to navigate the single-blind and double-blind peer-review processes, understand the legalities of Intellectual Property (IP), and recognize predatory publishing practices via Beall’s criteria. Furthermore, the syllabus proactively addresses the modern ethical dilemma of Artificial Intelligence in research, establishing strict guidelines for its disclosure and utilization.

Competitive Examination Alignment (CSIR-NET, GATE, JEST)

A defining strategic advantage of this academic framework is its meticulous, intentional alignment with the syllabi of India's premier national-level competitive examinations. The depth and sequencing of the coursework ensure that graduates are inherently prepared for these assessments without the strict necessity of external coaching.
- **Mathematical Methods:** The inclusion of complex analysis, contour integration, Green's functions, and advanced tensor calculus directly mirrors the CSIR-NET and GATE requirements.
- **Classical and Quantum Mechanics:** The transition from Lagrangian/Hamiltonian dynamics to canonical transformations and Hamilton-Jacobi theory provides the exact depth required for JEST

and NET. The comprehensive coverage of Clebsch-Gordan coefficients, WKB approximation, and relativistic quantum mechanics leaves no gaps in the national quantum theory syllabus.
- **Electrodynamics and Thermodynamics:** The rigorous derivations within electromagnetic wave propagation, gauge transformations, and the detailed formulations of partition functions and phase transitions map perfectly onto the core requirements of all major entrance exams.
- **Advanced Core Topics:** The syllabus exhaustively covers the specialized sections of the NET exam, including lattice dynamics, the nuclear shell model, particle physics symmetries ($SU(3)$ flavor, Gell-Mann-Okubo mass formula), and atomic coupling (L-S and j-j).

Pedagogical Dynamics and Evaluation Protocols

To achieve the stated Program Learning Outcomes, the pedagogical approach shifts from continuous lecturing to active, problem-based learning.

Instructional Delivery:

Theoretical concepts are delivered via formal lectures, immediately followed by mathematical tutorial sessions where students solve complex boundary value problems and formulate equations of motion. Applied concepts are taught through hands-on laboratory practicums, computational simulations (using Python and LTspice), and the critical review of peer-reviewed scientific literature.

Continuous Evaluation Matrix:

The assessment framework is designed to continuously measure both theoretical comprehension and practical execution.

- Formative Assessment (In-Semester - 30 Marks): This includes unit tests, computational assignments, classroom presentations, and continuous laboratory evaluations. This allows for real-time feedback and pedagogical adjustments.
- Summative Assessment (End-Semester - 70 Marks): Comprehensive written examinations that test higher-order cognitive skills—requiring students to derive complex physical laws, analyze hypothetical physical systems, and solve unseen mathematical problems.
- Project Defense: The research projects (RP-I to RP-IV) culminate in formal dissertations written in LaTeX and oral defenses before an academic panel. Students are evaluated on their literature review, experimental/theoretical methodology, error analysis, and their ability to defend their conclusions under academic scrutiny.

The M.Sc. Physics framework at Madhabdev University is a rigorous, modern, and highly demanding academic journey. It respects the legacy of classical physics while aggressively integrating the computational, ethical, and applied skills required to drive scientific innovation in the 21st century.

PG Program Structure
Department of Physics
Madhabdev University

Year	Semester	Course	Course Code and Title of the Course	Total Credits
Year 01	Semester 01	C-1	**PPYC 101:** Advanced Mathematical Physics	4
		C-2	**PPYC 102:** Advanced Electronics	4
		C-3	**PPYC 103:** Classical Mechanics	4
		C-4	**PPYC 104:** Research Methodology in Physics	4
		Research Project (RP-I)	**PPYC RP-I**: Research Project-I/Field Work	2
		Minor-7	**PPYN 101:** Electronics and Solid-State Physics	4
	Total of Semester 01			**22**
	Semester 02	C-5	**PPYC 201:** Quantum Mechanics and Applications	4
		C-6	**PPYC 202:** Electromagnetic Theory	4
		C-7	**PPYC 203:** Plasma Physics	4
		C-8	**PPYC 204:** Laboratory V	4
		Research Project (RP II)	**PPYC RP-II**: Research Project-II	4
		Minor	**PPYN 201:** Laboratory-II	4
	Total of Semester 02			**24**
	Grand Total (Semester 1 to 2)			**46**

A 4 year Under Graduate Degree (Honours) in Major discipline will be awarded who completes 174 credits. 4 year Under Graduate Degree (Honours with Research) will be awarded to those who secure 75% marks and above in the first six Semesters and who wish to undertake research at Under Graduate level. Those students who progress in 4 years Under Graduate Degree (Honours) in Major discipline have to complete one major paper in lieu of project.

One Year M.Sc. Programme

Year 02	**Semester 03**	**C-9**	**PPYC 301:** Atomic and Molecular Physics	4
		C-10	**PPYC 302:** Advanced Nuclear and Particle Physics	4
		C-11	**PPYC 303:** Laboratory VI	4
		DSE - I	A. **PPYC DSE IA:** General Relativity and Cosmology-I B. **PPYC DSE IB:** Condensed Matter Physics-I C. **PPYC DSE IC:** Applied Physics-I: Electronic Systems D. **PPYC DSE ID:** High Energy Physics-I	4
		RP-III	**PPYC RP-III**: Research Project	4
	Total of Semester 9			**20**
	Semester 04	**C-12**	**PPYC 401:** Advanced Quantum Mechanics	4
		C-13	**PPYC 402:** Advanced Statistical Mechanics	4
		C-14	**PPYC 403:** Astronomy, Space Science and Atmospheric Physics	4
		DSE - II	A. **PPYC DSE IIA:** General Relativity and Cosmology-II B. **PPYC DSE IIB:** Condensed Matter Physics-II C. **PPYC DSE IIC:** Applied Physics-II: Instrumentation Systems D. **PPYC DSE IID:** High Energy Physics-II	4
		RP-IV	**PPYC RP-IV**: Research Project	4
	Total of Semester 10			**20**
	Grand Total (Semester 1 to 4)			**86**
Students opting for 1 year M.Sc. must complete 40 credits.				

Syllabus for PG:
Semester I
Core 1

Course Type: Core Course
Paper Title: Advanced Mathematical Physics
Paper code: PPYC 101
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60 (39 Lectures + 21 Tutorials)

Course Objectives
To equip students with the advanced mathematical foundations required for postgraduate theoretical physics, focusing on abstract linear vector spaces, boundary value problems, symmetry through group theory, and the differential geometry of tensors.
Course Outcomes (COs) & Bloom's Taxonomy Mapping
Upon successful completion of this course, students will be able to:

1. Analyze linear vector spaces, diagonalize complex matrices, and apply the Cayley-Hamilton theorem to operator mechanics.
2. Construct solutions for inhomogeneous partial differential equations using Green's functions and evaluate linear integral equations.
3. Classify physical symmetries using discrete group representations, character tables, and continuous Lie groups (SU(2), SO(3)).
4. Formulate the geometric laws of physics using tensor calculus, covariant derivatives, and curvature tensors.

Course Content (End-Semester Marks: 70)

Unit I: Linear Vector Spaces and Matrices (22 Hours: 14L + 8T | 25 Marks)
Linear vector spaces: definition and examples, linear independence, basis and dimension, inner product, norm of a vector, orthonormal basis, Gram-Schmidt orthogonalization method, Schwarz's and Bessel's inequalities. Linear operators, matrix representation of linear operators. Special types of matrices: symmetric and antisymmetric, orthogonal, Hermitian and anti-Hermitian, unitary, normal. Eigenvalues and eigenvectors. Change of basis, similarity transformation, orthogonal and unitary transformations, diagonalization of matrices. **Cayley-Hamilton Theorem and its applications**. Infinite-dimensional vector spaces, Hilbert space.

Unit II: Partial Differential Equations and Integral Equations (14 Hours: 9L + 5T | 17 Marks)
Partial differential equations: method of separation of variables in Cartesian, spherical, and cylindrical coordinate systems. Laplace’s equation, Poisson’s equation, diffusion equation. Examples of boundary value problems in physics. Inhomogeneous differential equations and Green’s functions. Introduction to integral equations: linear integral equations of the first and second kind (Fredholm and Volterra equations).

Unit III: Group Theory (12 Hours: 8L + 4T | 14 Marks)
Groups: definition and examples. Groups of symmetry transformation: cyclic group, dihedral group, permutation group. Subgroups, Lagrange’s theorem, cosets, conjugacy classes. Group representation: reducible and irreducible representations, Schur’s lemmas, and character tables. Continuous or Lie groups,

generators of continuous groups. Special orthogonal groups: $SO(2)$, $SO(3)$. Unitary groups: U(1), SU(2).

Unit IV: Tensor Analysis (12 Hours: 8L + 4T | 14 Marks)
Basics of tensor algebra, contravariant and covariant tensors. Line element and metric tensor, associated tensors. Christoffel's symbols, geodesics, covariant derivatives. Riemannian Christoffel's tensor (curvature tensor), Bianchi identities. The Ricci tensor, Ricci scalar, and the Einstein tensor. Parallel transport.

Suggested Readings

1. **George B. Arfken and Hans J. Weber**, *Mathematical Methods for Physicists* (Academic Press).
2. **A.W. Joshi**, *Matrices and Tensors in Physics* (New Age International).
3. **A.W. Joshi**, *Elements of Group Theory for Physicists* (New Age International).
4. **Mary L. Boas**, *Mathematical Methods in the Physical Sciences* (Wiley).
5. A.K. Ghatak, I.C. Goyal, and S.J. Chua, *Mathematical Physics: Differential Equations and Transform Theory* (Macmillan).

Expected Learner Outcomes

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

1. **Apply** advanced linear algebraic principles, including vector space theory, matrix diagonalization, and the Cayley-Hamilton theorem, to solve problems in operator mechanics.
2. **Construct** analytical solutions for complex inhomogeneous partial differential equations using Green's functions and evaluate linear integral equations.
3. **Classify** physical symmetries through the application of group representations, character tables, and continuous Lie group theory.
4. **Formulate** the geometric laws of physics in a coordinate-invariant framework by utilizing tensor algebra, covariant derivatives, and curvature tensors.

Core 2

Course Type: Core Course
Paper Title: Advanced Electronics
Paper code: PPYC 102
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

This course equips students with the analog and digital electronics foundations required for experimental and instrumentation physics, focusing on sequential and timing circuits, microprocessor/microcontroller architecture and programming, feedback and oscillator theory in analog amplifiers, operational amplifier design, and analog-to-digital conversion techniques.

Course Outcomes (COs) & Bloom's Taxonomy Mapping

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

- **CO1 [Understand & Apply]:** Design timing/counting circuits and explain 8085/8051 architecture and programming.
- **CO2 [Analyze & Evaluate]:** Analyze feedback effects on amplifiers and evaluate oscillator circuits using the Barkhausen criterion.
- **CO3 [Understand & Apply]:** Explain op-amp characteristics and apply them to design linear and non-linear op-amp circuits.
- **CO4 [Apply & Create]:** Design D/A and A/D converters and apply FET devices in amplification and switching.

Course Content (End-Semester Marks: 70)

Section A: Digital Electronics

Unit I: Sequential Circuits (10 marks| 8L)

Flip-Flops and its types. IC 555: block diagram and applications: Astable multivibrator and Monostable multivibrator. Ring Counter. Asynchronous counters, Decade Counter. Synchronous Counter.

Unit II:Computer Architecture, Microprocessors, and Microcontrollers (18 marks|16L)

Data storage (idea of RAM and ROM).Computer memory.Memory organization & addressing. Memory Interfacing. Memory Map.

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

Introduction to 8051 microcontroller and embedded systems, instruction set, addressing mode, programming, time delay generation, look up table implementation etc.

Section B: Analog Electronics

Unit III: Feedback in Amplifiers: (8 marks|7L)

Effect of positive and negative feedback on Input impedance, Output impedance, Gain , Stability, Distortion and noise. . Two stage RC coupled Amplifier and its frequency response.

Unit IV: Sinusoidal Oscillators: (7 marks|7 L)

Barkhausen's Criterion for self-sustained oscillations. RC Phase shift oscillator, determination of Frequency. Hartley &Colpitts oscillators.

Unit V: Operational Amplifiers: (13 marks|10L)

Characteristics of an Ideal and Practical Op-Amp. (IC 741) Open-loop and Closed-loop Gain .Frequency Response. CMRR. Slew Rate and concept of Virtual ground.

Applications of Op-Amps:

(1) Inverting and non-inverting amplifiers, (2) Adder, (3) Subtractor, (4) Differentiator, (5) Integrator,

(6) Log amplifier, (7) Zero crossing detector (8) Wein bridge oscillator.

Unit VI: Conversion: (3 marks|3 L)

Resistive network (Weighted and R-2R Ladder). Accuracy and Resolution. A/D Conversion (successive approximation)

Unit VII: Integrated Circuits : (3 marks|3 L)

Active & Passive components. Discrete components. Wafer.Chip.Advantages and drawbacks of ICs. Scale of integration: SSI, MSI, LSI and VLSI (basic idea and definitions only). Classification of ICs.Examples of Linear and Digital ICs.

Unit VIII: Modern Semiconductor Devices : (8 marks|6L)

JFET, and MOSFET, structure, working, derivation of the equations of IV characteristics under different conditions, D- MOSFET, E- MOSFET, Digital switching, active load, introduction to CMOS, MESFET and FINFET technology. Silicon Controlled Rectifier (SCR): structure, working principle, V–I characteristics and applications.

Recommended readings:

- Digital Principles and Applications, A.P. Malvino, D.P.Leach and Saha, 7th Ed., 2011, Tata McGraw
  Fundamentals of Digital Circuits, Anand Kumar, 2nd Edn, 2009, PHI Learning Pvt. Ltd.
- Digital Circuits and systems, Venugopal, 2011, Tata McGraw Hill.
- Digital Electronics G K Kharate ,2010, Oxford University Press
- Digital Systems: Principles & Applications, R.J.Tocci, N.S.Widmer, 2001, PHI Learning

- Logic circuit design, Shimon P. Vingron, 2012, Springer.
- Digital Electronics, SubrataGhoshal, 2012, Cengage Learning.
- Digital Electronics, S.K. Mandal, 2010, 1st edition, McGraw Hill
- Integrated Electronics, J. Millman and C.C. Halkias, 1991, Tata Mc-Graw Hill.
- OP-Amps and Linear Integrated Circuit, R. A. Gayakwad, 4th edition, 2000, Prentice Hall
- Electronic circuits: Handbook of design & applications, U.Tietze, C.Schenk,2008, Springer
- Microprocessor Architecture Programming & applications with 8085, 2002, R.S. Goankar, Prentice Hall.

Expected Learning Outcomes: This course will enable a student to

- Learn to analyze circuits containing BJT along with the application of BJT oscillators.
- Develop basic knowledge of operational amplifier and its applications.
- Study timer and counter circuits
- Design and study analog to digital conversion techniques
- Develop basic codes for 8085 microprocessor.

Core-3

Course Type: Core Course
Paper Title: Classical Mechanics
Paper code: PPYC 103
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To provide students with a rigorous foundation in the advanced analytical formulations of classical mechanics, bridging the gap between Newtonian mechanics, continuous field theories, and modern non-linear dynamics/chaos.

Course Outcomes (COs) & Bloom's Taxonomy Mapping

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

- **CO1 [Understand & Apply]:** Apply variational calculus to formulate Lagrangian and Hamiltonian equations, and utilize Noether's theorem to link symmetries with conserved quantities.
- **CO2 [Apply & Analyze]:** Analyze complex dynamical systems, including classical scattering, precessing orbits in central fields, and coupled small oscillations.
- **CO3 [Analyze & Evaluate]:** Evaluate phase space dynamics using canonical transformations, Poisson brackets, and the Hamilton-Jacobi formalism.
- **CO4 [Evaluate & Create]:** Assess the stability of non-linear systems, interpret chaotic behavior, phase space attractors, and formulate the mechanics of continuous classical fields.

Course Content (End-Semester Marks: 70)

Unit I: Analytical Foundations and Symmetries (12 Lectures | 14 Marks)

Lagrangian Formulation: Generalized coordinates, constraints, D'Alembert's principle. Variational calculus, Action, and Hamilton's principle. Euler-Lagrange equations.

Hamiltonian Formulation: Legendre transformations, Hamilton's equations. Phase space trajectories. Liouville's theorem. Scaling laws and potential reconstruction.
Symmetries: Cyclic coordinates, conservation theorems. Continuous symmetries and an introduction to Noether's theorem for discrete particles.

Unit II: Central Force, Scattering, and Coupled Oscillations (12 Lectures | 14 Marks)
Central Force & Scattering: The Kepler problem, hidden symmetry (Runge-Lenz vector), perturbations, and precessing orbits. The classical scattering problem, differential cross-sections, and impact parameters.
Small Oscillations: Systems with many degrees of freedom. Expansion of kinetic and potential energies (non-diagonal terms). Eigenvalue equations, normal modes, and normal coordinates.

Unit III: Canonical Transformations and H-J Theory (12 Lectures | 14 Marks)
Canonical Framework: Canonical variables and Poisson brackets. Fundamental properties and equations of motion in Poisson bracket form.
Transformations: Canonical transformations, generators of infinitesimal transformations.
Hamilton-Jacobi Theory: The Hamilton-Jacobi equation, integrable canonical flows. Action and angle variables. Adiabatic invariants.

Unit IV: Rigid Body Dynamics and Classical Fields (12 Lectures | 14 Marks)
Rigid Body Dynamics: Linear transformations, rotations, and rotating frames. Definition of a rigid body, Eulerian angles, Euler's theorem. Angular momentum, kinetic energy, and the moment of inertia tensor. Euler's equations of motion, the heavy symmetrical top.
Continuous Systems: Systems with infinite degrees of freedom. Classical fields: Lagrangian and Hamiltonian formulations. Equations of motion for continuous fields.

Unit V: Non-Linear Dynamics and Deterministic Chaos (12 Lectures | 14 Marks)
Stability and Bifurcations: Flows in phase space, integrable vs. non-integrable systems. Equilibria and linear stability theory. Bifurcations in Hamiltonian systems.
Chaos Theory: Maps, winding numbers, return maps, and area-preserving maps. Deterministic chaos, strange attractors, period doubling, and Lyapunov exponents. Geometry and integrability in phase space.

Suggested Readings

1. **H. Goldstein, C. Poole, and J. Safko**, *Classical Mechanics* (Pearson)
2. **L.D. Landau and E.M. Lifshitz**, *Mechanics (Course of Theoretical Physics)* (Butterworth-Heinemann)
3. **Steven H. Strogatz**, *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering* (CRC Press)
4. **S.N. Biswas**, *Classical Mechanics* (Books & Allied)
5. **N.C. Rana and P.S. Joag**, *Classical Mechanics* (McGraw Hill)

Expected Learner Outcomes

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

1. **Formulate** equations of motion for complex mechanical systems using variational principles, Lagrangian, and Hamiltonian dynamics.
2. **Analyze** dynamical phenomena including central force motion, scattering problems, and coupled small oscillations in many-body systems.

3. **Evaluate** phase space dynamics and system integrability through the application of canonical transformations and Hamilton-Jacobi theory.
4. **Apply** symmetry principles and Noether's theorem to identify conserved quantities and resolve problems in rigid body dynamics.
5. **Interpret** non-linear dynamics, including deterministic chaos, strange attractors, and the mechanics of continuous classical fields.

Core-4

Course Type: Core Course
Paper Title: Research Methodology in Physics
Paper code: PPYC 104
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

- Expand error analysis protocols to include Maximum Likelihood Estimation (MLE), Monte Carlo uncertainty modeling, and rigorous hypothesis testing paradigms.
- Elucidate the operational principles and hardware architectures of critical analytical instrumentation.
- Develop research-level proficiency in signal processing, noise mitigation, transducer physics, and vacuum technology.
- Derive and analyze formal numerical algorithms for differentiation, integration, interpolation, and the Runge-Kutta 4th order (RK4) method.
- Analytically apply probability distributions, specifically Binomial, Poisson, and Normal models, to physical measurement challenges.
- Attain fluency in professional scientific authorship using the LaTeX typesetting system.
- Internalize the ethical frameworks of modern research, focusing on authorship integrity, data FAIRness, peer-review standards, and the role of Artificial Intelligence.

Course Outcomes (COs)

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

- **CO1 [Apply & Analyze]:** Execute Maximum Likelihood Estimation and Monte Carlo simulations for rigorous uncertainty quantification and validate experimental datasets through formal hypothesis testing.
- **CO2 [Understand]:** Deconstruct the operational block-diagrams and physical tenets of premier analytical instruments utilized in contemporary physics research.
- **CO3 [Understand & Apply]:** Model the behavior of signal, noise, and transducers within research environments, optimizing instrumentation selection for high-vacuum and low-noise applications.
- **CO4 [Analyze & Evaluate]:** Derivate and evaluate the convergence and stability of numerical differentiation, integration, interpolation, and ODE solvers (RK4).
- **CO5 [Apply]:** Synthesize Binomial, Poisson, and Normal probability distributions to characterize physical measurements and counting statistics.
- **CO6 [Create]:** Produce high-impact, professional scientific manuscripts and technical reports utilizing the LaTeX typesetting ecosystem.

- **CO7 [Understand & Evaluate]:** Critically assess ethical scientific conduct, navigating the nuances of data integrity, authorship taxonomies, peer-review, and AI utilization.

Unit I: Statistical Inference and Advanced Error Analysis (7 Lectures | 7 Marks)
Metrological concepts: Accuracy, precision, resolution, sensitivity, and calibration. Classification of errors: gross, systematic, and random errors. Propagation of uncertainties in single- and multivariable functions. Gaussian (Normal) distribution and standard deviation. Weighted mean and least-squares fitting. Chi-square (χ^2) test for goodness of fit. Introduction to Maximum Likelihood Estimation (concept only). Analysis and interpretation of experimental data using statistical methods.

Unit II: Signals, Noise, and Systems Theory (7 Lectures | 7 Marks)
Analytical study of periodic and aperiodic signals. Transfer functions and frequency response of higher-order systems. Transient response dynamics: rise time, overshoot, and settling time. Theoretical analysis of noise: Johnson (thermal), shot, and 1/f spectral densities. Signal-to-noise ratio (SNR) optimization, noise figure.

Unit III: Transducer Physics and Vacuum Technology (12 Lectures | 15 Marks)
Generalized performance of zero-, first-, and second-order measurement systems. Transducer signal conditioning and calibration. Physics of temperature sensors (RTDs/ thermistors/ thermocouples/ semiconductor sensors (AD590/LM35)). Position and force transducers: strain gauges, piezoelectric crystals, and LVDTs.

Radiation detection principles: ionization chambers and scintillation counters. Kinetic theory of gases applied to high-vacuum systems: pumping speeds of mechanical, diffusion, and turbomolecular pumps. Pressure monitoring via Pirani, Penning, and ionization gauges.

Unit IV: Analytical Spectroscopy and Chromatography (10 Lectures | 10 Marks)
UV-Visible Spectrophotometry: Electronic transitions, Beer–Lambert law, and block diagram of a spectrophotometer. **Infrared Spectroscopy and FTIR:** Molecular vibrations, basic principle, and Michelson interferometer. **Atomic Absorption Spectroscopy (AAS):** Principle, instrumentation, and applications. **Chromatography:** Principles and classification (paper, TLC, GC, HPLC). **Introduction to advanced characterization techniques:** Basic principles and applications of X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM).

Unit V: Numerical Methods and Differential Solvers (16 Lectures | 20 Marks)
Numerical differentiation via Taylor series expansions. Integration techniques: composite Trapezoidal and Simpson’s rules. Interpolation theory: Lagrange polynomials, Newton’s difference formulas. ODE solvers: analytical derivation of Euler and Runge-Kutta methods. Matrix algebra: iterative convergence (Jacobi/Gauss-Seidel).

Unit VI: Probability Theory and LaTeX Typesetting (5 Lectures | 6 Marks)
Probabilistic frameworks: conditional probability and Bayes' theorem. Discrete and continuous distributions: Binomial, Poisson (counting statistics), and Normal (Central Limit Theorem). Professional LaTeX typesetting: document structuring, mathematical environments (inline/display), figure/table embedding, and BibTeX citation management.

Unit VII: Research Ethics and Scientific Conduct (3 Lectures | 5 Marks)
Analysis of research misconduct: Fabrication, Falsification, and Plagiarism (FFP). Professional standards in authorship (CRediT taxonomy) and peer-review responsibilities. Data stewardship: FAIR principles and reproducibility. Intellectual property, predatory publishing mitigation (Beall’s criteria), and ethical AI disclosure policies.

Core Scholarly References

- Numerical Methods for Engineers — S. C. Chapra & R. P. Canale, McGraw Hill.
- An Introduction to Error Analysis — J. R. Taylor, University Science Books.
- Principles of Instrumental Analysis — D. A. Skoog, F. J. Holler, S. R. Crouch, Cengage.

- Introduction to Measurements and Instrumentation — A. K. Ghosh, PHI Learning.
- Statistical Methods in Experimental Physics — W. T. Eadie et al., North-Holland.
- The Not So Short Introduction to LaTeX — T. Oetiker et al.
- On Being a Scientist: A Guide to Responsible Conduct in Research — National Academies Press.
- The Vacuum Experimenter's Handbook — A. Chambers, Springer.

Semester II
Core-5

Course Type: Core Course
Paper Title: Quantum Mechanics and Applications
Paper code: PPYC 201
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives
To equip students with the abstract formalism of vector spaces, advanced approximation techniques for complex quantum systems, and the semiclassical treatment of radiation.

Course Outcomes (COs)
Upon successful completion, students will be able to:
- CO1 [Apply & Analyze]: Utilize Dirac notation, projection operators, and the algebraic method to analyze abstract quantum states and the harmonic oscillator.
- CO2 [Apply]: Calculate angular momentum additions and construct wavefunctions for systems of identical particles using the Pauli exclusion principle.
- CO3 [Analyze & Evaluate]: Apply time-independent approximation methods to compute fine structure corrections and energy shifts in atomic systems.
- CO4 [Evaluate]: Evaluate transition probabilities under time-dependent perturbations using Fermi's Golden Rule and analyze selection rules.

Course Content (End-Semester Marks: 70)
Unit I: Abstract Formalism, Operators, and Symmetries (15 Lectures | 17 Marks)
The Schrödinger, Heisenberg, and Interaction pictures, Dirac notation for state vectors (bra-ket formalism). Linear vector spaces and Hilbert space. Different types of Operators, Projection operators, generalized uncertainty relations, and change of basis. Symmetries and conservation laws in quantum mechanics. The Linear Harmonic Oscillator (LHO) by operator method (creation and annihilation operators).

Unit II: Angular Momentum (15 Lectures | 18 Marks)
Angular momentum algebra, commutation relations. Eigenvalues of J^2 and J_z. Stern-Gerlach experiment, Spin angular momentum and Pauli matrices, Addition of angular momenta and Clebsch-Gordan coefficients.

Unit III: Time-Independent Approximation Methods (15 Lectures | 18 Marks)
Time-independent perturbation theory (including degeneracy and non-degenerate cases) and applications. Spin-orbit coupling and fine structure of Hydrogen. The Variational method and its application to the Helium atom. The WKB approximation (connection formulas and bound states). The Stark effect and the Zeeman effect.

Unit IV: Time-Dependent Methods and Radiation (15 Lectures | 17 Marks)
Time-dependent perturbation theory. Fermi's golden rule and transition probabilities. Harmonic perturbations. Semi-classical theory of radiation: interaction of atoms with an electromagnetic field, emission and absorption of radiation, dipole approximation, and selection rules.

Suggested readings:

1. Modern Quantum Mechanics, J. J. Sakurai, Addison Wesley.
2. Quantum Mechanics, L. I. Schiff, McGraw Hill.
3. Quantum Mechanics, Bransden and Joachain, Pearson Education.
4. Quantum Mechanics, Powell and Craseman, Narosa Publishing House.
5. Quantum Mechanics, R. Shankar, Kluwer Academic.

6. Quantum Mechanics, D. J. Griffiths, Pearson Education.
7. Quantum Mechanics, Mathews and Venkatesan, McGraw Hill.
8. Quantum Mechanics, R. L. Liboff, Pearson Education.

Expected Learning Outcomes:

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

- Utilize the abstract formalism of Dirac notation, Hilbert space, and operator mechanics to perform rigorous analyses of quantum systems, such as the linear harmonic oscillator.
- Apply the algebraic laws of angular momentum and spin to construct wavefunctions for many-body systems of identical particles adhering to the Pauli exclusion principle.
- Evaluate energy shifts and fine structure corrections in atomic systems by applying advanced approximation methods, specifically time-independent perturbation theory, variational principles, and the WKB approximation.
- Formulate the semi-classical theory of radiation using Fermi's Golden Rule to determine transition probabilities and selection rules for systems undergoing time-dependent perturbations.

Core 6

Course Type: Core Course
Paper Title: Electro-Magnetic Theory
Paper code: PPYC 202
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Description: Electromagnetic Theory forms one of the fundamental pillars of modern physics, providing a unified framework for understanding electric and magnetic fields and their interactions. This course equips students with advanced mathematical and physical concepts necessary to analyze electromagnetic phenomena, wave propagation, radiation, and the behavior of charged particles. It serves as the foundation for specialized areas such as optics, plasma physics, microwave engineering, antenna theory, condensed matter physics, and quantum electrodynamics.

Course Objectives (CO)

1. Understand basic knowledge of Maxwell equations and their applications in various media.

2. Understand basic knowledge of polarization of EM wave.

3. Understand the basic knowledge of wave guide and its applications in optical fibers.

Learning Outcomes (LO)

1.Solve problems relevant to interfaces between media with defined boundary conditions.

2. Use Maxwell's equations to describe the behavior of electromagnetic waves in vacuum as well as medium.

3. Describe states and methods of polarization and analyze the polarization state of a light source.

Course Contents:

Unit I: Maxwell Equations: (L 13 M 15)

Review of Maxwell’s equations, Displacement Current, Vector and Scalar Potentials, Gauge Transformations: Lorentz and Coulomb Gauge, Boundary Conditions at Interface between Different Media, Wave Equations.Plane Waves in Dielectric Media, Poynting Theorem and Poynting Vector, Electromagnetic (EM) Energy Density, Physical Concept of Electromagnetic Field Energy Density, Momentum Density and Angular Momentum Density, Radiation from accelerated charge, radiation from electric dipole.

Unit II: EM Wave Propagation in Unbounded Media: (L 10 M 12)

Plane EM waves through vacuum and isotropic dielectric medium, transverse nature of plane EM waves, refractive index and dielectric constant, wave impedance. Propagation through conducting media, relaxation time, skin depth. Wave propagation through dilute plasma, electrical conductivity of ionized gases, plasma frequency, refractive index, skin depth, application to propagation through ionosphere.

Unit III: EM Wave in Bounded Media: (L 10 M 12)

Boundary conditions at a plane interface between two media. Reflection & Refraction of plane waves at plane interface between two dielectric media-Laws of Reflection & Refraction. Fresnel's Formulae for perpendicular & parallel polarization cases, Brewster's law. Reflection & Transmission coefficients. Total internal reflection, evanescent waves. Metallic reflection (normal Incidence)

Unit IV: Polarization of Electromagnetic Waves: (L 10 M 13)

Description of Linear, Circular and Elliptical Polarization. Propagation of E.M. Waves in Anisotropic Media. Symmetric Nature of Dielectric Tensor. Fresnel’s Formula. Uniaxial and Biaxial Crystals. Light Propagation in Uniaxial Crystal. Double Refraction. Polarization by Double Refraction. Nicol Prism. Ordinary & extraordinary refractive indices. Production & detection of Plane, Circularly and Elliptically Polarized Light. Phase Retardation Plates: Quarter-Wave and Half-Wave Plates. Babinet Compensator and its Uses. Analysis of Polarized Light

Unit V: Rotatory Polarization: (L 4 M 5)

Optical Rotation. Biot’s Laws for Rotatory Polarization. Fresnel’s Theory of optical rotation. Calculation of angle of rotation. Experimental verification of Fresnel’s theory. Specific rotation. Laurent’s half-shade polarimeter.

Unit VI: Wave Guides: (L 10 M 10)

Planar optical wave guides. Planar dielectric wave guide.Condition of continuity at interface. Phase shift on total reflection. Eigenvalue equations. Phase and group velocity of guided waves , Field energy and power transmission.

Unit VII: Optical Fibers: (L 3 M 3)

Numerical aperture , Step and Graded Indices (Definitions only), Single and Multimode fibres

References:

- Introduction to Electrodynamics, D.J. Griffiths, 3rd Ed., 1998, Benjamin Cummings.
- Elements of Electromagnetics, M.N.O. Sadiku, 2001, Oxford University Press.
- Introduction to Electromagnetic Theory, T.L. Chow, 2006, Jones & Bartlett Learning
- Fundamentals of Electromagnetics, M.A.W. Miah, 1982, Tata McGraw Hill
- Electromagnetic field Theory, R.S. Kshetrimayun, 2012, Cengage Learning
- Engineering Electromagnetic, Willian H. Hayt, 8th Edition, 2012, McGraw Hill.

Core 7

Course Type: Core Course
Paper Title: Plasma Physics
Paper code: PPYC 203
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Description:
With the recent increase in interest towards controlled fusion and widespread use of plasma in different industrial, agricultural and health sectors, in space research etc, there is a demand for the study of plasma physics. To fulfill this demand, the course on plasma physics is designed for the students to develop theoretical knowledge about plasma (both in nature and Laboratory) its applications and diagnostics.

Course Objectives (CO)

1.To Understand the fundamental concepts of plasma, its characteristics, classifications, and applications.

2.Analyze the motion of charged particles in electric and magnetic fields and understand particle confinement mechanisms.

3.Develop the fluid description of plasmas and relate plasma behavior to electromagnetic theory.

4.Explain the propagation of waves in plasmas and their significance in laboratory and space plasmas.

5.Understand the kinetic description of plasmas, including the Vlasov equation, MHD approximation, and Landau damping.

6.To Acquire introductory knowledge of laboratory plasma generation techniques and commonly used plasma diagnostic methods

Course Contents:

Unit I: Basics of Plasmas: Concepts of Plasmas: Definition, Plasma parameters, criterion of plasmas, concepts of plasma temperature, Debye shielding, classification of Plasmas, Application of plasmas. (**L= 6. M=8**)

Unit II: Charged Particles in Electro-magnetic fields: Motion of charged particles in electromagnetic fields: uniform E & B fields, guiding centre, non-uniform fields, grad-B and curvature drift, diffusion across magnetic fields, adiabatic invariants, magnetic mirror. (**L=14, M=18**)

Unit III: Plasma as Fluids: Introduction, Navier-Stoke's equation, Relation of plasma physics to ordinary electromagnetics, fluid equation of motion, fluid drifts perpendicular and parallel to B, plasma approximation. (**L=12, M=12**)

Unit IV: Waves in Plasmas: Plasma oscillations, electron plasma waves, ion acoustic waves, propagation of waves in presence of magnetic fields, dispersion relations, cut offs and Resonance, propagation through ionosphere, Van Allen Belts.(**L=16, M=18**)

Unit V: Kinetic theory of Plasmas:
Need for kinetic theory, Vlasov equation, MHD as approximation to kinetic theory, Landau Damping
(**L=8, M=8**)

Unit VI: Introduction to Laboratory Plasmas and Diagnostics:
Types of Laboratory Plasmas and production mechanism, Electrical Probes and Optical Diagnostics (OES and Laser based)in plasmas. (**L=4, M=6**)

References:

1. Introduction to plasma physics and Controlled Fusion, F. F. Chen, Plenum Press
2. Fundamentals of plasma physics, R. A. Bittencourt, Springer.
3. Introduction to Plasma Physics, R. J. Goldston and P. H. Rutherford, IoP Publishing
4. Principles of Plasma Discharges and Materials Processing, M.A.Lieberman and A.J.Lichtenberg, Wiley Interscience
5. Principles of plasma diagnostics, I. H. Hutchinson, Cambridge University Press.

Learning Outcomes (LO)

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

1. Explain the basic properties of plasmas, plasma parameters and criterion, Debye shielding and sheath formation, plasma temperature,
2. Solve problems involving charged particle motion in uniform and non-uniform electromagnetic fields, including particle drifts and magnetic mirror effects.
3. Apply fluid equations to describe plasma behavior and distinguish between fluid and kinetic approaches to plasma physics.
4. Analyze plasma oscillations, wave propagation, dispersion relations, cut-offs, resonances, and ionospheric plasma phenomena.
5. Describe the kinetic theory of plasmas using the Vlasov equation and explain the concepts of MHD approximation and Landau damping.
6. Identify different laboratory plasma sources and explain the principles of basic plasma diagnostic techniques such as electrical probes, optical emission spectroscopy (OES), and laser-based diagnostics.
7. Appreciate the applications of plasma physics in fusion research, space science, materials processing, and industrial technologies.

Core-8

Course Type: Core Course
Paper Title: Laboratory V
Paper code: PPYC 204
Credits: 4 (Practical/Laboratory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

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

1. Experimentally verify fundamental laws and principles of electromagnetism.
2. Investigate the behavior of electromagnetic waves in different mediums.
3. Construct and analyze flip-flop circuits for sequential logic operations.
4. Develop skills in programming the 8085 microprocessor for arithmetic and control tasks.
5. Design and characterize analog circuits using operational amplifiers, transistors, and timers.
6. Study frequency response, oscillation, and amplification properties of electronic circuits.
7. Design and study sensor based systems for measurement of various physical parameters

Supports: Electronics II (7th-sem theory) · EMT & Non-linear Optics · Plasma Physics · Total experiments: 48

Group A — Electronics II Practicum (22 experiments)

Carried forward as-is from 7th-semester Electronics II theory paper (no 7th-semester lab)

1. Flip-Flop (RS, Clocked RS, D-type, JK) circuits using NAND gates
2. JK Master-slave flip-flop using Flip-Flop ICs
3. 4-bit Counter using D-type/JK Flip-Flop ICs; study of timing diagram
4. 4-bit Shift Register (serial and parallel) using D-type/JK Flip-Flop ICs
5. Astable multivibrator of given specifications using a 555 Timer
6. Monostable multivibrator of given specifications using a 555 Timer
7. 8085 Microprocessor programs: addition/subtraction (direct and indirect addressing), multiplication by repeated addition, division by repeated subtraction, 16-bit number handling, CALL/RETURN, block data handling, and one further program (e.g. parity check or interrupt handling)
8. Frequency response of voltage gain of an RC-coupled transistor amplifier
9. Wien bridge oscillator for a given frequency using an op-amp
10. Phase-shift oscillator of given specifications using a BJT
11. Colpitts oscillator

12. Digital-to-analog converter (DAC) of given specifications
13. Analog-to-digital converter (ADC) IC
14. Inverting amplifier using an op-amp (741/351) for a DC voltage of given gain
15. Inverting amplifier using an op-amp — frequency response
16. Non-inverting amplifier using an op-amp — frequency response
17. Zero-crossing detector and comparator
18. Adding two DC voltages using an op-amp in inverting and non-inverting mode
19. Precision differential amplifier of given I/O specification using an op-amp
20. Op-amp as an integrator
21. Op-amp as a differentiator
22. Circuit to simulate the solution of a 1st/2nd order differential equation

Group B — EMT, Non-linear Optics & Plasma Physics (21 experiments)

Plasma Physics experiments merged into this group

1. Verification of the law of Malus for plane-polarized light
2. Specific rotation of sugar solution using a polarimeter
3. Analysis of elliptically polarized light using a Babinet's compensator
4. Radiation pattern of a simple dipole antenna vs angle
5. Wavelength and velocity of ultrasonic waves in a liquid (kerosene, xylene) via diffraction through an ultrasonic grating
6. Reflection and refraction of microwaves
7. Polarization and double-slit interference in microwaves
8. Refractive index of a liquid by total internal reflection using Wollaston's air-film
9. Refractive index of glass and a liquid by total internal reflection using a Gaussian eyepiece
10. Polarization of light by reflection; determination of the polarizing (Brewster) angle for an air-glass interface
11. Verification of Stefan's law of radiation; determination of Stefan's constant
12. V-I characteristics of a PN junction diode: determination of the Boltzmann constant and the semiconductor energy band gap
13. Calibration curve of a Jamin's interferometer; refractive index of air
14. Wavelength of a monochromatic source using Michelson's interferometer; Sodium D-line splitting
15. Wavelength of a monochromatic source using a Fabry-Perot interferometer; Sodium D-line splitting
16. Wavelength of He-Ne laser light
17. Wavelength of laser light via single-slit diffraction, double-slit diffraction, and a plane diffraction grating (with angular spread)
18. Velocity of sound using a CRO
19. Thermal conductivity of a bad conductor by Lee and Charlton's disc method
20. Ionization potential of mercury (electron-impact ionization in a vapour)
21. Complex dielectric constant and plasma frequency of a metal using Surface Plasmon Resonance (SPR)

Group C — Computational Physics (Python) (5 experiments)

Python, NumPy, root-finding, and statistical-distribution methods are assumed prior knowledge and are not repeated here

1. Numerical solution of the s-wave radial Schrödinger equation for the hydrogen atom (ground and first excited state) by the shooting method; plot of energy eigenvalues and wavefunctions
2. Numerical solution of the s-wave radial Schrödinger equation for a screened Coulomb potential; ground-state energy for varying screening length
3. Molecular-dynamics simulation of a Lennard-Jones gas: equilibrium density fluctuations, approach to equilibrium, velocity distribution vs Maxwell distribution
4. Numerical solution of the radioactive decay equation ($dN/dt = -\lambda N$) by the Runge-Kutta method; comparison with the analytic exponential solution
5. Preparation of a scientific report with numerical results, tables, and graphs using LaTeX

Recommended readings:

- Advanced Practical Physics for students, B.L. Flint and H.T. Worsnop, 1971, Asia Publishing
- House.
- Advanced level Physics Practicals, Michael Nelson and Jon M. Ogborn, 4th Edition, reprinted
- 1985, Heinemann Educational Publishers
- A Text Book of Practical Physics, I.Prakash& Ramakrishna, 11th Ed., 2011, KitabMahal
- Electromagnetic Field Theory for Engineers & Physicists, G. Lehner, 2010, Springer
- Modern Digital Electronics, R.P. Jain, 4th Edition, 2010, Tata McGraw Hill.
- Basic Electronics: A text lab manual, P.B. Zbar, A.P. Malvino, M.A. Miller, 1994, Mc-Graw Hill.
- Microprocessor Architecture Programming and applications with 8085, R.S. Goankar, 2002, Prentice Hall.
- Microprocessor 8085:Architecture, Programming and interfacing, A. Wadhwa, 2010, PHI Learning.

Expected Learner Outcomes: This course will enable students to

1. Experimentally verify fundamental laws and principles of electromagnetism.
2. Experimentally verify different sequential circuits and familiarize with 8085 microprocessor programming
3. Design and study instrumentation systems and measure physical parameters for scientific purposes.

Semester III

Core 9

Course Type: Core Course
Paper Title: Atomic and Molecular Physics
Paper code: PPYC 301
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To establish a foundation in the quantum mechanical description of atomic systems, investigate the spectral behavior of atoms in electric and magnetic fields, and provide a comprehensive understanding of molecular spectroscopy and laser physics.

Course Outcomes (COs)

Upon successful completion, students will be able to:

• **CO1 [Understand & Apply]:** Explain the theoretical formulation of quantum mechanics regarding atomic structure, including Bohr's model and the vector atom model.

• **CO2 [Analyze]:** Analyze the fine structure of atomic spectra and the influence of external electric and magnetic fields (Zeeman, Paschen-Back, Stark effects).

• **CO3 [Apply]:** Utilize the theory of molecular spectra, including rotation, vibration, and Raman scattering, to solve physical problems.

• **CO4 [Evaluate]:** Interpret the behavior of many-electron atoms, including spin-orbit coupling, term symbols, and spectral notations.

Course Content (End-Semester Marks: 70)

Unit I: Quantum Theory of Atoms (08 Lectures | 10 Marks)

Background of Quantum Theory: Bohr's model of the hydrogen atom, origin of spectral lines, Bohr's correspondence principle, Sommerfeld's atom model, designation of spectral term symbol. Vector atom model, space quantization, Larmor precession, the four quantum numbers, spectral terms arising from L-S coupling and j-j coupling, selection rules.

Unit II: Fine structures of atoms and impacts of Electric & Magnetic Fields (16 Lectures | 20 Marks)

Fine structure of hydrogen spectra, doublet spectra of Na-atom. Gyromagnetic ratio for orbital and spin motion, Lande's 'g' factor, strong and weak field effects, Zeeman Effect (normal and anomalous), Paschen Back and Stark Effect (Qualitative Discussion only).

Electron angular momentum. Space quantization. Electron Spin and Spin Angular Momentum. Larmor's Theorem. Spin Magnetic Moment. Stern-Gerlach Experiment. Electron Magnetic Moment and Magnetic Energy, Gyromagnetic Ratio and Bohr Magneton.

Unit III: Molecular spectra and lasers (18+08 Lectures | 20+10 Marks)

Molecular Physics: Regions of the spectrum, types of molecules, Rotational Spectra for rigid and non rigid rotators, isotopic effect in rotational spectra, intensity of spectral lines, information derived from rotational spectra, Vibrational spectra for anharmonic oscillator, vibration-rotation spectra, Electronic spectra of molecules- Born Oppenheimer approximation, vibrational analysis of electronic band spectra, fine structure of electronic band spectra, Fortrat Diagram, Raman spectra, Spin resonance spectroscopy- NMR, ESR, Mössbauer spectroscopy, Fourier Transform Spectroscopy.

Lasers: Fundamentals of Lasers-properties, basic elements, threshold condition, rate equations: two, three and four levels. Population inversion, Laser resonator and modes, Ammonia Masers, types of laser: solid state laser, gas laser, semi conductor laser, applications of laser spectroscopy, Laser Cooling.

Unit IV: Many electron atoms (10 Lectures | 10 Marks)

Pauli's Exclusion Principle. Symmetric & Antisymmetric Wave Functions. Periodic table. Fine structure. Spin-orbit coupling. Spectral Notations for Atomic States. Total angular momentum. Vector Model. Spin-orbit coupling in atoms-L-S and J-J couplings. Hund's Rule. Term symbols. Spectra of Hydrogen and Alkali atoms (Na etc.)

Suggested Readings:

1. Atomic Physics, J.B. Rajam, S. Chand and Company
2. Fundamentals of Molecular Spectroscopy, Banwell and McCash, Tata McGraw Hill
3. Molecular Structure and Spectroscopy, G. Aruldhas, Prentice Hall of India
4. Atomic Spectra, H.E. White, McGraw Hill
5. Modern Physics, G. Aruldhas and P. Rajagopal, Prentice Hall of India

Expected Learner Outcomes:

This course will enable students to:

1. Apply quantum mechanics to solve physical systems in different areas of science.
2. Understand the physical behavior of materials at the atomic level.
3. Learn how the scientific behavior of materials (such as in lasers and spectroscopy) can be utilized for human applications.

Core 10

Course Type: Core Course
Paper Title: Advanced Nuclear and Particle Physics
Paper code: PPYC 302
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To elevate the students' understanding of subatomic physics by applying advanced quantum mechanics to the two-body problem, complex nuclear models, the formal theory of nuclear reactions and decays, and the gauge symmetries of the Standard Model.

Course Outcomes (COs)

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

◦ CO1 [Apply & Analyze]: Analyze the nucleon-nucleon interaction using the deuteron ground state, tensor forces, and partial wave analysis of low-energy scattering.

◦ CO2 [Analyze]: Evaluate nuclear structure using the extreme single-particle shell model (Schmidt lines) and the collective model (rotational/vibrational spectra).

◦ CO3 [Evaluate]: Evaluate transition probabilities and selection rules for beta and gamma decays using Fermi's theory and multipole radiation expansions.

◦ CO4 [Apply & Create]: Formulate nuclear reaction cross-sections using the Breit-Wigner resonance and optical models, and classify elementary particles using SU(3) flavor symmetry.

Course Content (End-Semester Marks: 70)

Unit I: The Two-Body Problem and Nuclear Forces (12 Lectures | 14 Marks)

Ground state of the deuteron, magnetic dipole and electric quadrupole moments. Presence of non-central (tensor) forces. Nucleon-Nucleon (N-N) scattering at low energies: partial wave analysis, scattering length, and effective range theory. Spin-dependence of N-N forces. High-energy N-N scattering (qualitative). Exchange forces, the meson theory of nuclear forces (Yukawa potential), isotopic spin formalism, and the generalized Pauli exclusion principle.

Unit II: Advanced Nuclear Models (12 Lectures | 14 Marks)

Note: Liquid Drop Model and Basic Shell Model assume prior knowledge.

Extreme single-particle shell model: spin-orbit coupling, predictions of magnetic and electric moments (Schmidt lines). Residual interactions. The Collective model: evidence of collective motion, vibrational and rotational spectra of deformed nuclei. Qualitative introduction to the Nilsson model for deformed nuclei.

Unit III: Formal Theory of Nuclear Decays (12 Lectures | 14 Marks)

Beta Decay: Fermi's theory of beta-decay, shape of the beta spectrum, Kurie plots, comparative half-lives (ft-values). Allowed and forbidden transitions, selection rules. Parity non-conservation in weak interactions (Wu's experiment) and the helicity of the neutrino.

Gamma Decay: Multipole radiation, quantum mechanical transition probabilities (Weisskopf estimates), selection rules. Internal conversion and nuclear isomerism.

Unit IV: Advanced Nuclear Reactions (12 Lectures | 14 Marks)

Note: Basic kinematics and Q-values assume prior knowledge.

Partial wave analysis of nuclear reactions. The Optical model (complex potential). Compound nucleus theory (Bohr's hypothesis), Breit-Wigner single-level resonance formula (with and without spin). Direct reactions: stripping and pick-up reactions (kinematics and qualitative theory, Butler's theory). Qualitative discussion of heavy-ion collisions.

Unit V: Advanced Particle Physics and Symmetries (12 Lectures | 14 Marks)

Note: Basic particle classification assumes prior knowledge.

Continuous and discrete symmetries. Charge conjugation (C), Parity (P), and Time reversal (T) operations; the CPT theorem. CP violation in neutral Kaon decay. SU(2) isospin symmetry. SU(3) flavor symmetry, the Gell-Mann-Nishijima formula, and the Gell-Mann-Okubo mass formula. The Quark model (meson and baryon nonets). Introduction to weak isospin, gauge bosons, and the fundamental framework of the Standard Model.

Suggested Readings

1. Kenneth S. Krane, Introductory Nuclear Physics (John Wiley & Sons) — The foundational text bridging the gap to advanced topics.
2. Roy and Nigam, Nuclear Physics: Theory and Experiment (New Age International) — Excellent for the two-body problem and scattering.
3. M.A. Preston and R.K. Bhaduri, Structure of the Nucleus (Westview Press) — The definitive text for advanced nuclear models.
4. David Griffiths, Introduction to Elementary Particles (Wiley-VCH) — The gold standard for Unit V.
5. W.E. Burcham and M. Jobes, Nuclear and Particle Physics (Prentice Hall).

Expected Learning Outcomes

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

1. **Analyze** the fundamental nature of nucleon-nucleon interactions by interpreting deuteron properties and scattering data through partial wave analysis.
2. **Evaluate** nuclear structure by applying the single-particle shell model and collective models to describe nuclear spectra and electromagnetic moments.
3. **Formulate** theoretical models for beta and gamma decay, applying Fermi's theory and selection rules to predict transition probabilities.
4. **Apply** advanced nuclear reaction theories, such as the optical model and Breit-Wigner resonance, to interpret scattering cross-sections.
5. **Classify** elementary particles and characterize their interactions by utilizing SU(3) flavor symmetry and the framework of the Standard Model.

Core 11

Course Type: Core Course
Paper Title: Laboratory VI
Paper code: PPYC 303
Credits: 4 (Practical/Laboratory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Supports: Quantum Mechanics (8th-semester theory) · Atomic & Molecular Physics · Nuclear Physics · DSEs · Total experiments: 35

Group A — Quantum, Atomic, Molecular & Nuclear Physics (13 experiments)

Quantum Mechanics experiments (theory: 8th semester) scheduled here for reinforcement after theory completion; Nuclear Physics experiment merged into this group

1. Planck's constant using black-body radiation and a photodetector
2. Photoelectric effect: photocurrent vs intensity and wavelength; stopping potential/maximum photoelectron energy vs frequency
3. Work function of the filament material of a directly heated vacuum diode
4. Planck's constant using LEDs of at least four different colours
5. Wavelength of the H-alpha emission line of hydrogen
6. Absorption lines in the rotational spectrum of iodine vapour
7. e/m of the electron by magnetic focusing
8. Millikan oil-drop apparatus: charge of the electron
9. Tunnelling effect in a tunnel diode via I-V characteristics
10. Study of the normal and anomalous Zeeman effect
11. e/m of the electron by the magnetron method
12. Electron spin resonance (ESR)
13. Geiger-Müller (GM) counter: counting statistics and detector characteristics

Group B — Solid State & Materials Physics (9 experiments)

Supports DSE I / DSE II semiconductor, sensor, and materials content

1. Magnetic susceptibility of a paramagnetic solution (Quincke's tube method)
2. Magnetic susceptibility of solids
3. Coupling coefficient of a piezoelectric crystal
4. Dielectric constant of a dielectric material vs frequency
5. Refractive index of a dielectric layer using SPR
6. P-E hysteresis loop of a ferroelectric crystal
7. B-H curve of Fe using a solenoid; determination of hysteresis energy loss
8. Resistivity of a semiconductor (Ge) via the four-probe method (room temperature to 150°C); determination of band gap
9. Hall coefficient of a semiconductor sample

Group C — Experimental Techniques (13 experiments)

Supports DSE I / DSE II instrumentation content; carried forward as-is

1. LVDT output characteristics and displacement measurement
2. Strain measurement using a strain gauge
3. Level measurement using a capacitive transducer
4. Characteristics of a thermistor; determination of its parameters
5. Distance measurement using an ultrasonic transducer
6. Calibration of a semiconductor temperature sensor (AD590, LM35, or LM75)
7. Temperature measurement using a Resistance Temperature Device (RTD)
8. Vacuum generation using a rotary pump; pressure measurement using a pressure gauge

9. Comparison of noise pickup in cables (coaxial, single-shielded, double-shielded, unshielded); importance of grounding
10. Design and study of a Sample-and-Hold circuit
11. Design and analysis of clippers and clampers using a junction diode
12. Frequency response of a microphone
13. Measurement of the Q of a coil using a Q-meter

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: General Relativity and Cosmology - I
Paper code: PPYC DSE IA
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To teach students the physical and mathematical foundations of Einstein's relativistic theory of gravitation, focusing on tensor calculus, the derivation of field equations, exact solutions, and observational signatures like the black hole shadow.

Course Outcomes (COs) & Bloom's Taxonomy Mapping

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

◦ **CO1 [Apply & Analyze]:** Execute tensor analysis operations and analyze curved spacetime geometries using Christoffel symbols and Riemann curvature tensors.

◦ **CO2 [Understand & Apply]:** Explain the principles of equivalence and covariance, and formulate Einstein's field equations from the action principle.

◦ **CO3 [Analyze]:** Deconstruct the Schwarzschild solution to characterize the nature of singularities, event horizons, photon spheres, and black hole shadows.

◦ **CO4 [Evaluate]:** Assess the validity of General Relativity by evaluating classical experimental tests and Post-Newtonian approximations.

Course Content (End-Semester Marks: 70)

Unit I: Mathematical Foundations and Tensor Analysis (15 Lectures | 17 Marks)

Equality of gravitational and inertial masses, Weak and Strong Equivalence principles, Principle of general covariance. Covariant and contravariant tensors, tensors of arbitrary rank, metric tensor. Parallel transport and covariant differentiation. Affine connection. Curvature tensor (Riemann) and its symmetries, Bianchi identities, Weyl tensor, and conformal invariance.

Unit II: Einstein's Field Equations (15 Lectures | 18 Marks)

Equation of motion of particles (timelike and null geodesics). Energy-momentum tensor for a perfect fluid and dust. Action principle for field equations. Einstein's field equation: gravity as curvature of spacetime. Conservation laws in curved space and pseudo-energy tensor. Weak fields and the Newtonian approximation of gravity.

Unit III: Exact Solutions and Black Hole Signatures (15 Lectures | 17 Marks)

The Schwarzschild exterior solution. Birkhoff's theorem. Radial motion towards the center. Symmetries and Killing vectors. Kruskal-Szekeres coordinates. Nature of singularities, black holes vs. naked singularities, the event horizon. Null geodesics around compact objects, photon spheres, and the theoretical foundation of the Black Hole Shadow.

Unit IV: Applications and Experimental Tests (15 Lectures | 18 Marks)

General orbits, constants of motion. Classical tests: Deflection of light, precession of the perihelion of Mercury, gravitational redshift, and radar echo delay (Shapiro effect). Standard, isotropic, and harmonic coordinates. Parametrized post-Newtonian (PPN) formalism and the status of observational verifications. Mach's principle.

Suggested Readings:

1. Mathematical Methods for Physicists, G. B. Arfken and H. J. Weber, Elsevier Academic Press.
2. Mathematical Physics : Basics, S. D. Joglekar, Universities Press.
3. Mathematical Physics : Advance, S. D. Joglekar, Universities Press.
4. Tensor Calculus, Barry Spain, Radha Publishing House (Kolkata).
5. General Theory of Relativity, P. A. M. Dirac, Prentice-Hall of India.
6. Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, S. Weinberg, Wiley and Sons.
7. T. Padmanabhan, Gravitation: Foundations and Frontiers (Cambridge University Press, Cambridge, 2012).
8. V. Perlick and O. Yu. Tsupko, Calculating black hole shadows: Review of analytical studies, Physics Reports 947, 1 (2022).
9. R. C. Pantig and A. Övgün, Gravitational black hole shadow spectroscopy, Phys. Rev. D 112, 124072 (2025).
10. M. Wang, S. Chen, and J. Jing, Chaotic shadows of black holes: a short review, Commun. Theor. Phys. 74, 097401 (2022).
11. S. V. M. C. B. Xavier, H. C. D. Lima Junior, and L. C. B. Crispino, Shadows of black holes with dark matter halo, Phys. Rev. D 107, 064040 (2023).
12. L. Susskind, Three Lectures on Complexity and Black Holes (Springer International Publishing, Cham, 2020).
13. L. Susskind and J. Lindesay, An Introduction to Black Holes, Information and the String Theory Revolution: The Holographic Universe (WORLD SCIENTIFIC, 2004).
14. S. M. Carroll, Spacetime and Geometry: An Introduction to General Relativity, 1st ed. (Cambridge University Press, 2019).
15. J. B. Hartle, Gravity: An Introduction to Einstein's General Relativity, 1st ed. (Cambridge University Press, 2021).
16. C. W. Misner, K. S. Thorne, J. A. Wheeler, and D. Kaiser, Gravitation (Princeton University Press, Princeton, N.J, 2017).

Expected learner outcome: This course will

1. Enable students to master the mathematical framework of tensor analysis and differential geometry required for understanding curved spacetime.
2. Provide a deep conceptual understanding of the Equivalence Principles and the derivation of Einstein's Field Equations.
3. Develop the analytical ability to solve the Einstein equations for exact solutions, specifically the Schwarzschild metric.
4. Equip students with the skills to analyze high-gravity astrophysical phenomena, including black hole shadows, singularities, and photon spheres.
5. Enable students to critically evaluate the General Theory of Relativity through its classical experimental tests and post-Newtonian approximations.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: Condensed Matter Physics - I
Paper code: PPYC DSE IB
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Unit I: Review on Crystallography (L 8, Marks 10):

Crystal structures, crystal plane, reciprocal lattice. X-Ray diffraction, Bragg's law in terms of reciprocal lattice, Laue, Powder and Rotating Crystal method, Scattering Factor, Structure Factor.

Unit II: Lattice vibrations (L 13, Marks 15):

Harmonic approximation, monatomic and diatomic linear lattices, dispersion relations, normal modes, Phonons, Phonon creation and annihilation operators, elastic scattering of electrons by phonon, inelastic scattering of photons by phonons, inelastic scattering of neutrons by phonons, inelastic phonon- phonon scattering, infrared absorption in ionic crystals, lattice specific heat, anharmonic effects, thermal expansion, the Grueneisen parameter, normal and umklapp processes.

Unit III: Transport properties of solid (L 13, Marks 15):

Free electron theory, Energy levels and density of states, Fermi energy, Periodic potential, Bloch theorem, Kronig Penney model, Electronic energy bands, E-k diagram, Brillouin zone, Effective mass, metals, insulators and semiconductors. Tight binding approximation

Unit IV Dielectric and Ferroelectric Properties (L 13, Marks 15)

Static dielectric constant of solids, complex dielectric constant & dielectric loss, dielectric relaxation, Debye equation. Ferroelectric effect, dipole theory of ferroelectricity, Piezoelectric effect, Pyroelectric effect, Electrostrictive effect, anti-ferroelectricity.

Unit-V: Optical Properties of Solids (L 13, Marks 15)

Optical constants, dispersion relation of optical constants from Maxwell's equations, Kramers-Kronig relations, optical absorption and emission in semiconductors, exciton absorption, impurity and interband transitions, luminescence, thermoluminescence. UV, FTIR , p-n junction rectifiers Photovoltaic device principles, solar cell, temperature effect, solar cell materials, efficiency.,

Suggested Books

1. Solid State Physics, A J Dekker
2. Fundamentals of Solid-State Physics, J R Christman
3. Introduction to Solid State Physic, C Kittel
4. Solid State Theory, W. Harrison

Expected learner outcomes: This course will enable students to:

1. Characterize crystal structures using reciprocal lattice theory and interpret X-ray diffraction patterns.
2. Analyze lattice dynamics, including phonon dispersion relations and their contribution to thermal properties.
3. Explain electronic transport in solids using the free electron theory, band structure models (Bloch theorem), and tight-binding approximations.
4. Evaluate the dielectric, ferroelectric, and optical properties of materials, including device-level understanding of p-n junctions and photovoltaic cells.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: Applied Physics-I: Electronic Systems
Paper code: PPYC DSE IC
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Prerequisite: Electronics I & II (Semesters III & IV)

Course Objectives

To broaden the student's existing knowledge of electronics toward IC-centric signal conditioning, power semiconductor devices, and the fundamentals of communication; furthermore, to introduce contemporary digital hardware architectures and data acquisition methodologies essential for experimental physics research.

Course Outcomes (COs)

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

- CO1 [Analyze]: Determine and select the most suitable linear and digital integrated circuit modules for specific signal-processing requirements.
- CO2 [Understand]: Articulate the functional mechanics of power electronic components and their utility in regulated power conversion.
- CO3 [Describe]: Explain the theoretical framework of digital communication and the standard protocols employed for instrument-to-computer interfacing.
- CO4 [Evaluate]: Critically compare microprocessor, FPGA, and VLSI technologies while tracing the historical progression of circuit integration scales.
- CO5 [Apply]: Design the fundamental architecture of a data acquisition system and validate sampling parameters for experimental scenarios.

Pedagogy

Instruction delivered via formal lectures, complemented by practical circuit demonstrations, computational simulations (LTspice), and the analytical study of technical data sheets.

Course Content (End-Semester Marks: 70)

Unit I: Applications of Linear and Digital ICs (10 Lectures | 12 Marks)

Operational amplifier applications: comparator, Schmitt trigger, instrumentation amplifier, active filters (Butterworth, Sallen–Key). Voltage Controlled Oscillator (VCO). Analog-to-Digital and Digital-to-Analog converters: single-slope, dual-slope and successive-approximation ADCs; R–2R ladder DAC. Phase Locked Loop (PLL): basic principle and applications.

Unit II: Power Electronics: Devices and Applications (6 Lectures | 8 Marks)

SCR: structure, operation and triggering methods. Phase control using SCR. Power MOSFET and IGBT. DC–DC converters: Buck, Boost and Buck–Boost converters. Linear voltage regulators and Switched Mode Power Supplies (SMPS): principles, efficiency and applications.

Unit III: Communication Interfaces and Data Acquisition Systems (12 Lectures | 14 Marks)

Analog and digital modulation: AM, FM, ASK, FSK and PSK(Basic Concepts). Sampling theorem and quantization. Pulse Code Modulation (PCM). Delta Modulation. Serial communication interfaces: UART, RS-232, RS-485, I^2C and SPI. Data acquisition systems: architecture, sensor interfacing, multiplexing, signal conditioning, and computer interfacing. Introduction to virtual instrumentation.

Unit IV: Modern Digital Systems: (12 Lectures | 14 Marks)

Evolution of processor architectures: CISC and RISC concepts. ARM Cortex-M processors and ESP32 microcontrollers: architecture, peripherals and applications. FPGA: architecture, applications and comparison with microcontrollers.

Introduction to Hardware Description Languages (Verilog and VHDL). Evolution of integrated circuits from SSI to System-on-Chip (SoC). Digital hardware design flow: specification, HDL design, verification, synthesis, fabrication, packaging and testing (concept only).

Unit V: Physics of Modern Semiconductor Devices (10 Lectures | 12 Marks)

MOSFET scaling and short-channel effects. FinFET and Gate-All-Around (GAA) transistors. Wide bandgap semiconductors (SiC and GaN): material properties and applications. Semiconductor memories: SRAM, DRAM and Flash memory. Emerging semiconductor materials: graphene and transition metal dichalcogenides (concept only). Applications of modern semiconductor devices in power electronics, communication and sensing.

Unit VI: Semiconductor Manufacturing and Ecosystem (10 Lectures | 10 Marks)

Silicon crystal growth (Czochralski process) and wafer preparation. Semiconductor fabrication: oxidation, photolithography, ion implantation, thin-film deposition, etching and metallization. Packaging, testing and yield. Semiconductor industry models: IDM, Fabless and Foundry. Introduction to EDA tools and the semiconductor design-to-manufacturing workflow (concept only).

Evaluation Scheme

The assessment involves an end-semester examination (70 marks), internal unit tests and assignments (20 marks), and an optional mini-project or laboratory exercise (10 marks) focused on practical implementation (e.g., FPGA tasking or sensor interfacing).

<u>Reference books:</u>

- Semiconductor Physics and Devices, Donald A. Neamen, McGraw-Hill.
- The Art of Electronics, P. Horowitz and W. Hill, Cambridge University Press
- Electronic Instrumentation, H.S. Kalsi, Tata McGraw Hill
- Electronic Devices and Circuits, D.A. Bell, Oxford University Press
- Power Electronics Handbook, M.H. Rashid, Elsevier
- FPGA Prototyping by VHDL Examples, P. Chu, John Wiley & Sons
- Op-Amps and Linear Integrated Circuits, R.A. Gayakwad, Pearson Education
- Semiconductor Devices: Physics and Technology, S.M. Sze and M.K. Lee, John Wiley & Sons
- Communication Systems, Simon Haykin, John Wiley & Sons
- FPGA-Based System Design, Wayne Wolf, Prentice Hall.
- CMOS VLSI Design: A Circuits and Systems Perspective, N. H. E. Weste and David Harris Pearson.

Expected Learning Outcomes

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

1. Explain the operation and applications of modern analog, digital and power electronic circuits used in instrumentation and embedded systems.
2. Describe communication techniques, data acquisition systems and serial communication interfaces employed in scientific and industrial applications.
3. Understand the architecture and applications of modern embedded processors, microcontrollers, FPGA-based systems and Hardware Description Languages.
4. Explain the fundamental steps involved in semiconductor fabrication, packaging, testing, and the semiconductor design-to-manufacturing workflow.
5. Describe the semiconductor fabrication process, industry ecosystem and career opportunities in semiconductor technology.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: High Energy Physics - I
Paper code: PPYC DSE ID
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

Upon successful completion of this course, a student will be able to:

- **Classify** elementary particles and analyze their fundamental interactions.
- **Analyze** the mathematical formulation of group theory as applied to particle physics.
- **Apply** group theory to the quark model and interpret different particle interactions.
- **Express** physical quantities fluently using natural units.
- **Explain** the physics and derivation of relativistic wave equations.

Unit I: Introduction to Elementary Particles (20 Lectures | 24 Marks)

Historical introduction and classification of elementary particles. Intrinsic properties of elementary particles. Behavior of elementary particles under fundamental discrete symmetries: Charge Conjugation (C), Parity (P), Time Reversal (T), and G-parity. The Gell-Mann-Nakano-Nishijima law. The Eightfold Way (Gell-Mann and Ne'eman classification).

Unit II: Group Theory and The Quark Model (25 Lectures | 28 Marks)

Symmetries in physics, Lie groups, unitary and special unitary groups (U(1), SU(2), and SU(3)). Tensor method in SU(n), Young tableaux. Isospin symmetry, the quark model, and quark-mass formulas. The Zweig rule, quark color, and hadron wave functions. Quark model predictions: magnetic moments and hadron masses.

Unit III: Relativistic Wave Equations (15 Lectures | 18 Marks)

Natural units, Lorentz covariance, and four-vector notation. The Klein-Gordon equation. The Dirac equation and its covariant form, Dirac gamma matrices, adjoint equation, and conserved current. Solutions of the Dirac equation (free particle spinors), negative energy states, antiparticles, normalization of spinors, and completeness relations. Lorentz covariance of the Dirac equation, bilinear covariants. The Dirac equation for zero-mass particles (the two-component neutrino) and helicity states.

Mode of Assessment

Total Marks: 100

1. In-Semester Assessment (30 Marks)

- **Written Test:** 20 Marks
- **Continuous Assessment:** 10 Marks (Assignments, Presentations, Attendance, Classroom Interaction, and Quizzes)

2. End-Semester Examination (70 Marks)

- Comprehensive written examination covering all three units.

Expected Learning Outcomes

After the completion of this course, it is expected that the student will:

- Acquire foundational knowledge of elementary particles and their interactions, forming a basis for advanced theoretical physics.

- Successfully apply the mathematical framework of group theory to particle physics problems.
- Be rigorously prepared for advanced, graduate-level topics in quantum field theory and high-energy particle physics.
- Develop a strong motivation and academic foundation to pursue a research career in high-energy physics.

Suggested Readings

1. **Introduction to Elementary Particles**, D. J. Griffiths (John Wiley & Sons).
2. **Quarks and Leptons**, Francis Halzen and Alan D. Martin (John Wiley & Sons).
3. **Introduction to High Energy Physics**, Donald H. Perkins (Cambridge University Press).
4. **Gauge Theory of Elementary Particle Physics**, T. P. Cheng and L. F. Li (Oxford University Press).
5. **Physics of Elementary Particles**, H. Muirhead (Pergamon Press).

Semester IV

Core 12

Course Type: Core Course
Paper Title: Advanced Quantum Mechanics
Paper code: PPYC 401
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To transition students to the modern frameworks of theoretical physics, including the formal theory of scattering, relativistic wave equations, many-body second quantization, and introductory quantum field theory.

Course Outcomes (COs)

Upon successful completion, students will be able to:

◦ **CO1 [Analyze]:** Formulate scattering amplitudes, phase shifts, and cross-sections utilizing the Born approximation and partial wave analysis.

◦ **CO2 [Understand & Analyze]:** Analyze relativistic quantum wave equations, the covariant properties of Dirac spinors, and negative energy states.

◦ **CO3 [Apply & Evaluate]:** Formulate many-body problems using the formalism of second quantization and evaluate degenerate quantum gases.

◦ **CO4 [Evaluate & Create]:** Analyze the canonical quantization of classical fields, evaluate the density matrix formalism for mixed states, and analyze quantum entanglement.

Course Content (End-Semester Marks: 70)

Unit I: Advanced Symmetries and Identical Particles (20 Lectures | 20 Marks)

Advanced Symmetries: Tensor operators, spherical tensors, and the Wigner-Eckart theorem. Application of the Wigner-Eckart theorem to selection rules. **Identical Particles:** The postulate of indistinguishability, symmetric and antisymmetric wavefunctions. The spin-statistics connection and Pauli exclusion principle. Construction of multi-particle states using Slater's determinant. Exchange operator and exchange interactions. **Many-Body Basics:** Introduction to degenerate quantum gases (Bose-Einstein and Fermi-Dirac statistics).

Unit II: Elementary Theory of Scattering (15 Lectures | 17 Marks)

Kinematics of scattering (laboratory and center-of-mass frames). Scattering amplitude and differential/total cross-sections. The Lippmann-Schwinger equation and Green's functions. The method of partial waves, phase shifts, and the optical theorem. Low energy scattering and resonance scattering. The Born approximation and its validity (applications to Yukawa and Coulomb potentials).

Unit III: Relativistic Quantum Mechanics (15 Lectures | 18 Marks)

Review of special relativity. The Klein-Gordon equation: free particle solutions, negative energy states, and the problem of probability density. The Dirac equation for a free particle. Dirac matrices (\$\alpha\$, \$\beta\$) and their properties. Covariant form of the Dirac equation. Spin of the Dirac particle, Zitterbewegung, and hole theory. Ideas of second quantisation, Quantization of Klein Gordon and Dirac fields.

Unit IV: Quantum Information (10 Lectures | 15 Marks)

Pure and mixed states, the density matrix formalism, Quantum entanglement, Bell's theorem, and basic quantum information protocols (qubits and quantum teleportation), EPR Paradox, Quantum computation.

Suggested readings:

1. Modern Quantum Mechanics, J. J. Sakurai, Addison Wesley.
2. Quantum Mechanics, L. I. Schiff, McGraw Hill.
3. Quantum Mechanics, Bransden and Joachain, Pearson Education.
4. Quantum Mechanics, Powell and Craseman, Narosa Publishing House.
5. Quantum Mechanics, R. Shankar, Kluwer Academic.
6. Quantum Mechanics, D. J. Griffiths, Pearson Education.
7. Quantum Mechanics, Mathews and Venkatesan, McGraw Hill.
8. Quantum Mechanics, R. L. Liboff, Pearson Education.
9. Field Quantization, W. Greiner, J. Reinhardt, Springer.
10. A First Book of Quantum Field Theory, A. Lahiri, P.B. Pal, Narosa.

Expected learner outcome: This course will

1. Enable students to transition to modern theoretical frameworks, including formal scattering theory and relativistic wave equations.
2. Develop the ability to formulate and solve scattering problems using the Born approximation and partial wave analysis.
3. Provide deep insight into relativistic quantum mechanics, including the Dirac equation and second quantization of fields.
4. Enable students to utilize the density matrix formalism and understand the foundations of quantum information, including entanglement.

Core 13

Course Type: Core Course
Paper Title: Advanced Statistical Mechanics
Paper code: PPYC 402
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives:

The Statistical Mechanics is one of the most important branches of physics which is required to understand the properties matter in bulk on the basis of the dynamical behaviors of its microscopic constituents. As such the objectives of this course are:

1. To introduce the advance concepts of Statistical Mechanics so that students will be equipped with a sufficient knowledge of the subject.
2.To develop the critically thinking ability of students to understand the diverse physical phenomena.
3. To develop the interest and ability among students to solve challenging physical problems by the application of techniques of Statistical Mechanics in future.

Course Content:

Unit I: Introduction and formulation of Quantum Statistics (L 10, Marks 13)

Historical introduction of statistical mechanics, ergodic hypothesis, ensembles, partition function, grand partition function, postulates of quantum statistical mechanics, density matrix, pure and mixed states, density matrix and partition function of a system of free particles, classical limit of the partition function, BE and FD statistics.

Unit II: Ideal Bose and Fermi systems (L 15, Marks 15)

Ideal Bose gases, Bose-Einstein condensation, thermodynamic behaviour of an ideal Fermi gas, Pauli paramagnetism, Landau diamagnetism.

Unit III: Statistical Mechanics of Interacting systems (L 18, Marks 20)

Clusters, classical cluster expansion, formalism of second quantization, creation and annihilation operators and their properties for bosons and fermions, Hamiltonian in terms of second quantized operators, imperfect Bose and Fermi gases.

Unit IV: Phase transitions (L 10, Marks 12)

Dynamical model of phase transition, the Ising model (one dimension), liquid helium, He-4 and He-3, the lambda-transition, Tisza's two-fluid model, the theories of Landau and Feynman, equilibrium properties near absolute zero, superfluidity.

Unit V: Fluctuations (L 7, Marks 10)

Mean square deviation, fluctuation in ensembles, thermodynamic fluctuations, spatial correlation in a fluid, Einstein-Smoluchowski theory of Brownian motion, approach to equilibrium: the Fokker-Planck equation.

Suggested Readings:

1. Statistical Mechanics, R. K. Patharia, Butterwork Heinemann.

2. Statistical Mechanics, K. Huang, John Wiley and Sons.

3. Statistical Mechanics, K. M. Khanna, Today and Tomorrow, New Delhi.

4. Statistical Mechanics, B. K. Agarwal, M. Eisner, New Age International Publishers.

5. Fundamentals of Statistical Mechanics, B.B. Laud, New Age International Publishers.

6. A Primer of Statistical Mechanics, R. B. Singh, New Age International Publishers

Core:14

Course Type: Core Course
Paper Title: Astronomy, Space Science and Atmospheric Physics
Paper code: PPYC 403
Credits: 4 (Theory) – Distribution: Astronomy (2 Credits), Space Science (1 Credit), Atmospheric Physics (1 Credit)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

To integrate rigorous observational and theoretical astrophysics with the complex dynamics of planetary systems and Earth's atmosphere, emphasizing stellar evolution, space exploration, climate dynamics, and the historical legacy of Indian astronomical contributions.

Course Outcomes (COs) & Bloom's Taxonomy Mapping

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

- CO1 [Remember & Understand]: Explain observational techniques, coordinate systems, and historic IKS astronomical advancements, alongside stellar and galactic evolution.
- CO2 [Understand & Analyze]: Analyze solar dynamics and compare the physical environments of planetary systems utilizing data from major space missions.
- CO3 [Apply & Analyze]: Apply thermodynamic laws and radiative transfer equations to model atmospheric stability, scattering processes, and cloud microphysics.
- CO4 [Evaluate & Create]: Evaluate anthropogenic forcing agents in climate change and critically assess IPCC-aligned mitigation and resilience frameworks.

Course Content (End-Semester Marks: 70)

Unit I: Observational Astronomy and Historical Perspectives (20 Lectures | 22 Marks)

Trigonometric parallax, apparent and absolute magnitude systems, distance modulus, celestial coordinate systems, and the measurement of astronomical time. Optical, radio, and space-based telescopes; resolving power, photometry, spectrophotometry, and multi-wavelength astronomy.

Early measurements by Eratosthenes and Hipparchus. Seminal contributions of Aryabhatta I, Varahamihira, and Brahmagupta. The symbiotic relation between mathematics and astronomy; evidence of precession in Vedic literature; Jai Singh and the Jantar Mantar. Indian contributions in modern astrophysics and cosmology, Black hole man of India - C. V. Vishveshwara.

Unit II: Stellar and Galactic Astrophysics (15 Lectures | 18 Marks)

Stellar luminosity, surface temperature, spectral classification (OBAFGKM), and mass-luminosity correlations. The Hertzsprung-Russell (HR) diagram. Introduction to stellar structure (hydrostatic equilibrium in stars) and stellar evolution (from molecular clouds to compact remnants). Types of stars, black holes, wormholes etc. Basic nucleosynthesis. The Interstellar Medium (ISM). Structure and kinematics of the Milky Way galaxy. Hubble's classification of galaxies (ellipticals, spirals, irregulars). Introduction to Active Galactic Nuclei (AGNs) and quasars.

Unit III: Planetary Systems and Space Science (13 Lectures | 15 Marks)

Interior structure of the Sun, solar atmosphere (photosphere, chromosphere, corona), sunspots, the 11-year solar magnetic cycle, solar flares, coronal mass ejections (CMEs), and the solar wind. Physical properties and chemical composition of solar system planets and satellites. Differences between Terrestrial and Jovian planets, gas and ice giants. Meteorites and asteroids. Martian dust devils, Venusian lightning, Jovian weather, Great Red Spot, and tidal heating. Overview of space explorations by ISRO, ESA, and NASA. Impact of space weather on terrestrial systems.

Unit IV: Atmospheric Physics, Dynamics, and Climate (12 Lectures | 15 Marks)

Layers of the Earth's atmosphere, stratospheric ozone chemistry (Chapman cycle, ozone hole). Absorption and scattering of solar radiation (Rayleigh and Mie scattering). Principles of radiative transfer: Beer-Bouguer-Lambert law and Schwarzschild's equation. Hydrostatic equation, environmental lapse rate, and atmospheric stability (Brunt-Vaisala frequency). Adiabatic cooling and the Clausius-Clapeyron equation. Basic cloud microphysics (nucleation, Bergeron process). The natural greenhouse effect vs. enhanced global warming. Climate forcing agents. Indian monsoon and El-Nino. The role of the IPCC and Sustainable Development Goals (SDGs). Mitigation strategies: Carbon sequestration, renewable energy transitions, and geoengineering.

Suggested Readings:

1. Observational Astronomy, D. Scott Birney, Cambridge University Press.
2. The Cosmic Perspective,J. Bennettt, M. Donahue, N. Schneider and M.Voit, Pearson Addison Wesley.
3. An Introduction to Astrophysics, B. Basu, Prentice-Hall of India.
4. Astrophysics: Stars and Galaxies, K. D. Abhyankar, Orient Longman.
5. Spherical Astronomy, F. Brunnow, Van Nostrand.
6. Practical Astronomy, George L. Hosmer, John Wiley and Sons.
7.Meteorology for Scientists and Engineers, R. Stull, Brooks/Cole, Thomson Learning.
8. Atmospheric Chemistry and Physics, J. H. Seinfeld and S. N. Pandis, John Wiley and Sons.
9. Introduction to Atmospheric Physics, D. G. Andrews, Cambridge University Press.
10. Fundamentals of Atmospheric Modeling, M. Z. Jacobson, Cambridge University Press.
11. An Introduction to Atmospheric Radiation, K. N. Liou, Academic Press.
12. Stratosphere-Troposphere Interaction, K. Mohankumar, Springer.
13. The Atmosphere: An Introduction to Meteorology, F. K. Lutgens and E. J. Tarbuck, Prentice Hall.
14. The Atmosphere and Climate of Mars, Haberle, R., Clancy, R., Forget, F., Smith, M., & Zurek, R. (Eds.)., Cambridge: Cambridge University Press.
15. MARS: An Introduction to its interior, surface and Atmosphere, Nadine Barlow, Cambridge University Press.
16. Planetary Atmospheres, F. W. Taylor, Wiley.
17. Atmospheric Evolution on Inhabited and Lifeless Worlds, Cambridge University Press, ISBN-9781139020558.
18. NASA, ESA and ISRO websites for updated information.

Expected learner outcomes: This course will enable a student to:

1. Master observational techniques and coordinate systems to interpret stellar and galactic evolution, while appreciating historical Indian astronomical advancements.
2. Analyze the dynamics of the Sun and planetary systems, evaluating data from modern space missions and the impacts of space weather on terrestrial systems.
3. Apply thermodynamic laws and radiative transfer models to understand atmospheric stability, scattering processes, and cloud microphysics.
4. Evaluate the mechanisms of anthropogenic climate change and critically analyze mitigation strategies and resilience frameworks aligned with global sustainability goals.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: General Relativity and Cosmology - II
Paper code: PPYC DSE IIA
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives

This course extends GR into advanced relativistic astrophysics, black hole thermodynamics, and the Lambda-CDM cosmological model. It introduces the limitations of classical GR, exploring modified gravity, quantum gravity paradigms, and the physics of gravitational waves.

Course Outcomes (COs) & Bloom's Taxonomy Mapping

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

◦ **CO1 [Analyze & Evaluate]:** Analyze metric solutions for compact stars and rotating black holes, and evaluate the laws of black hole thermodynamics.

◦ **CO2 [Understand & Analyze]:** Interpret the dynamics of the Lambda-CDM cosmological model, including the thermal history of the Universe and the dark sector.

◦ **CO3 [Understand & Evaluate]:** Critique the limitations of classical General Relativity and compare alternative frameworks like f(R) gravity, String Theory, and Loop Quantum Gravity.

◦ **CO4 [Apply & Analyze]:** Apply the weak-field approximation to derive gravitational wave equations and analyze their polarization modes and detection methodologies.

Course Content (End-Semester Marks: 70)

Unit I: Relativistic Astrophysics and Black Hole Thermodynamics (18 Lectures | 21 Marks)

Oppenheimer-Volkoff and Tolman equations. Metric for uniform density stars. White dwarfs, Chandrasekhar limit, neutron stars, and pulsars. Reissner-Nordstrom metric. The Kerr solution, uniqueness theorem, Ergosphere, and the Penrose process. Zeroth, First, Second, and Third laws of black hole mechanics. Smarr's formula and Hawking radiation. Thermal stability of black holes, Joule-Thomson expansion of AdS black holes and topological thermodynamics.

Ideas of Wormholes, Warp Drives (Alcubierre Drive), ultra compact stars etc.

Unit II: The Standard Cosmological Model (Lambda-CDM) (16 Lectures | 19 Marks)

Cosmological principle, maximally symmetric spaces, Robertson-Walker (RW) metric. Redshift, Hubble's law, and the deceleration parameter. Friedmann equations and standard models (closed, flat, open). Critical density. Thermal history: Hot Big Bang, radiation/matter decoupling, and the CMBR. The standard Lambda-CDM model. Galaxy clusters and the missing mass problem (Dark Matter dynamics). The accelerating universe, cosmological constant, and Dark Energy (quintessence, phantom fields).

Unit III: Beyond General Relativity and the Early Universe (14 Lectures | 16 Marks)

The Planck era, Big Bang nucleosynthesis, the inflation paradigm, scalar fields, baryon asymmetry, and topological defects. Limitations of GTR: Ultraviolet divergences, spacetime singularities, and non-renormalizability. Introduction to alternative/modified theories of gravity: f(R) gravity and extensions, higher order gravity etc. Conceptual introductions to String Theory (extra dimensions, graviton) and Loop Quantum Gravity (spin networks, quantization of space). Stellar properties, black holes, wormholes, gravitational waves etc. in modified gravity framework and recent researches in this direction (basic idea).

Unit IV: Gravitational Radiation (12 Lectures | 14 Marks)

Weak field approximation, linear wave equation. Plane waves, transverse-traceless (TT) gauge, the standard plus and cross polarization modes. Generation: Emission by a rotating/accelerating source (quadrupole formula). Methods of detection: Ground-based laser interferometers (LIGO/Virgo/KAGRA), space-based observatories (LISA), and Pulsar Timing Arrays (PTAs).

Suggested Readings:

1. Mathematical Methods for Physicists, G. B. Arfken and H. J. Weber, Elsevier Academic Press.
2. Mathematical Physics : Basics, S. D. Joglekar, Universities Press.
3. Mathematical Physics : Advance, S. D. Joglekar, Universities Press.
4. Tensor Calculus, Barry Spain, Radha Publishing House (Kolkata).
5. General Theory of Relativity, P. A. M. Dirac, Prentice-Hall of India.
6. Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, S. Weinberg, Wiley and Sons.
7. T. Harko and F. S. N. Lobo, Extensions of f(R) Gravity: Curvature-Matter Couplings and Hybrid Metric-Palatini Gravity (Cambridge University Press, Cambridge, 2019).
8. D. Liang, Y. Gong, S. Hou, and Y. Liu, Polarizations of gravitational waves in f (R) gravity, Phys. Rev. D 95, 104034 (2017).
9. Y.-Q. Dong, Y.-Q. Liu, and Y.-X. Liu, Polarization modes of gravitational waves in general modified gravity: General metric theory and general scalar-tensor theory, Phys. Rev. D 109, 044013 (2024).
10. B. Schutz, A First Course in General Relativity, 3rd ed. (Cambridge University Press, 2022).
11. J. B. Hartle, Gravity: An Introduction to Einstein’s General Relativity, 1st ed. (Cambridge University Press, 2021).
12. C. W. Misner, K. S. Thorne, J. A. Wheeler, and D. Kaiser, Gravitation (Princeton University Press, Princeton, N.J, 2017).
13. S.-W. Wei and Y.-X. Liu, Topology of black hole thermodynamics, Phys. Rev. D 105, 104003 (2022).
14. S. W. Hawking, Particle creation by black holes, Commun. Math. Phys. 43, 199 (1975).
15. J. Bekenstein, Black holes and the second law, Lett. Nuovo Cim. 4, 737 (1972).
16. J. D. Bekenstein, Black holes and entropy, Phys. Rev. D 7, 2333 (1973).
17. Y. S. Duan and M. L. Ge, SU (2) gauge theory and electrodynamics of N moving magnetic monopoles, Sci. Sin. 9, 1072 (1979).
18. M. Alcubierre, The warp drive: hyper-fast travel within general relativity, Class. Quantum Grav. 11, L73 (1994).
19. A. Einstein and N. Rosen, The Particle Problem in the General Theory of Relativity, Phys. Rev. 48, 73 (1935

Expected learner outcome: This course will enable students to:

1. Analyze metric solutions for compact stars and rotating black holes, and evaluate the laws of black hole thermodynamics.
2. Interpret the dynamics of the Lambda-CDM cosmological model, including the thermal history of the Universe and the dark sector.
3. Critique the limitations of classical General Relativity and compare alternative frameworks like f(R) gravity, String Theory, and Loop Quantum Gravity.
4. Apply the weak-field approximation to derive gravitational wave equations and analyze their polarization modes and detection methodologies.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: Condensed Matter Physics - II
Paper code: PPYC DSE IIB
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Unit-I: Studies on ceramic material (Marks 12):

Electronic, ionic and mixed ionic conductor, Cationic, anionic, protonic, solid electrolyte, oxygen ion conductor, Jonscer's universal power law, Nernst's Einstein equation, dielectric and ceramic material, Different synthesis techniques and characterisation, Impedance spectroscopy, complex impedance, complex dielectric behaviour, electric modulus study.

Unit II: Sensor material and design, smart material (Marks 14):

Transduction-based sensor classification: piezoelectric (quartz, PZT), pyroelectric, magnetostrictive, thermoelectric, magnetoresistive (GMR, CMR) origins and material systems (manganites, multilayers); Piezoelectricity: direct/converse effects, coefficients, ferroelectric vs non-ferroelectric variants, PZT ceramic systems; Smart materials definition and external stimuli responsiveness; Shape Memory Alloys (SMA): martensitic-austenitic phase transformation, shape memory effect, superelasticity, Nitinol system; Electrostrictive and magnetostrictive materials: field-induced strain, Terfenol-D; Electrochromic and photochromic mechanisms; Electrorheological (ER) and magnetorheological (MR) fluids particle-suspension mechanics; Materials-level design figures of merit: sensitivity, hysteresis, fatigue, and response time.

Unit-III: Thin Films preparation and characterisations (Marks 10):

Definition of a thin film, different methods of film preparation: thermal evaporation, sputtering. Film thickness measurement: optical interference methods and other methods, Nature of thin films, theories of size effect, some thin film devices. conductivity of thin films, effect of thickness on transport properties, elementary concepts of surface crystallography, surface structure analysis of thin films, SEM, TEM and AFM

Unit IV: synthesis of Nanomaterials and characterisations (Marks 10):

Definition of nanomaterials, Types of nanomaterials: Metal, semiconductor (elemental and compound), methods of preparation. Quantum confinement: One, Two and Three-dimensional. Electrical, Optical and magnetic properties of nanomaterials. Nanomaterial based devices: Electronic, photonic, spintronics.

Unit-V: Soft material (Marks 10):

Definition of soft matter, Different types of soft matter: Liquid Crystals, Polymers: high polymers and conducting polymers, Surfactants, Biological materials, Correlated and uncorrelated systems, Nonlinear dynamics in soft matter, Recent studies on soft condensed matter.

Unit VI: Optical and high frequency effects in semiconductors (Marks 14):

Introductory Concepts of semiconductor, Rectifying properties of barriers, Schottky theory of M.S contact, surface states, p-n junction rectifiers Photovoltaic device principles, solar cell, temperature effect, solar cell materials, efficiency., optical constants, free carrier absorption, fundamental absorption, direct and indirect transitions. Electronic interband and intraband transitions, relation between optical properties and band structure, optical constants, luminescence

Suggested Books

1. Handbook of Thin Films, Maissel and Glang
2. Thin Film, Ashok Goswami
3. Introduction to Nanotechnology, C P Poole and F J Owens
4. Soft Condensed Matter, R A L Jones
5. B. Tarrev, Physics of dielectric materials, Mir Publishers, Moscow,

6. J. R. Macdonald, ed. Impedance spectroscopy--Emphasizing solid materials and systems. New York: Wiley-Interscience;
7. C. Suryanarayana, M Grant. Norton, X-ray Diffraction A Practical Approach, Plenum Press, New York,
8. B. D. Cullity, "Elements of X-ray Diffraction", Addison-Wesley Publishing Co. Inc.,

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: Applied Physics - II: Instrumentation Systems
Paper code: PPYC DSE IIC
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Prerequisite: Applied Physics I (DSE I) recommended

Course Objectives

To introduce advanced sensing technologies encompassing MEMS, intelligent sensors, and functional nanomaterials; to provide a rigorous foundation in biomedical instrumentation and signal recovery; and to familiarize students with the IoT and AI/ML paradigms within modern research instrumentation.

Course Outcomes (COs)

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

- CO1 [Understand]: Explain MEMS fabrication modalities and nanomaterial synthesis routes for high-sensitivity sensing applications.
- CO2 [Apply]: Design biopotential amplifiers and describe the physiological origin of ECG, EEG, and EMG signals.
- CO3 [Analyze]: Analyze closed-loop industrial control systems, specifically PI, PD, and PID controller architectures.
- CO4 [Describe]: Articulate the role of IoT connectivity and communication protocols in remote laboratory monitoring.
- CO5 [Evaluate]: Critique appropriate machine learning models for processing time-series experimental data.
- CO6 [Create]: Conceptualize digital twins and utilize Finite Element Method (FEM) tools for predictive instrument modeling.

Pedagogy

Instruction combines formal lectures with research case studies, computational modeling demonstrations, and the critical review of peer-reviewed scientific literature.

Course Content (End-Semester Marks: 70)

Unit I: MEMS, Smart Sensors, and Nanomaterials (13 Lectures | 15 Marks)

MEMS fabrication: bulk and surface micromachining; accelerometers and gyroscopes. Smart sensors: self-calibration and sensor fusion (Kalman filtering). Nanomaterial-based sensors: surface-to-volume effects, chemical and green synthesis, UV–Vis spectroscopy and Surface Plasmon Resonance (SPR) characterization. Metal oxide, plasmonic/colorimetric and carbon-based nanosensors.

Unit II: Signal Conditioning and Biomedical Applications (12 Lectures | 14 Marks)

Advanced signal recovery: Phase-sensitive detection and lock-in amplification. Signal-to-noise ratio (SNR), sensor sensitivity, noise floor and bandwidth.

Physics of biopotentials: Nernst potential, action potential, Ag/AgCl electrodes and biopotential amplifiers (high CMRR and isolation). Fundamentals of ECG, EEG and EMG signal acquisition. IEC 60601-1 safety standards.

Unit III: Industrial and Process Instrumentation (11 Lectures | 13 Marks)

Industrial process variables: transmitters and the 4–20 mA current loop. Control theory: proportional and derivative actions; PID controller tuning methodologies. Programmable Logic Controllers (PLC) and ladder logic. SCADA architectures for research infrastructure. Mechanical actuation via servo and stepper motor drives.

Unit IV: IoT and Connected Instrumentation (5 Lectures | 6 Marks)

IoT stack for scientific applications: perception and edge layers. Utilization of ESP32 as a connected telemetry node. The MQTT protocol for instrument data streaming. Design of remote-access dashboards for laboratory monitoring.

Unit V: AI and Machine Learning in Physical Measurement (7 Lectures | 8 Marks)

Machine learning workflows: Classification vs regression, Supervised learning workflow: feature extraction, training and validation. Model performance metrics: F1-score and Cohen's kappa in noisy datasets. Classification via random forest and SVM. Deep learning: 1D CNNs and Recurrent Neural Networks (LSTM/GRU) for physical time-series. Introduction to Physics-Informed Neural Networks (PINNs) and TinyML for edge computing.

Unit VI: Digital Twin, Simulation, and Quantum Sensing (12 Lectures | 14 Marks)

Digital twin synchronization: merging physical instruments with virtual models. Finite Element Method (FEM) in COMSOL/ANSYS for MEMS and fluid dynamics. Foundations of quantum sensing: NV centers in diamond, atomic magnetometers, and optical lattice clocks. Trends in wearable flexible electronics and neuromorphic event-driven sensing.

Evaluation Scheme

Students assessed through end-semester examination (70 marks), internal assignments (20 marks), and an optional lab-based project focused on sensor synthesis or PID simulation (10 marks).

Reference books:

- Medical Instrumentation: Application and Design, J.G. Webster, John Wiley & Sons
- The Art of Electronics, P. Horowitz and W. Hill, Cambridge University Press
- *Internet of Things: A Hands-On Approach*, Arshdeep Bahga and Vijay Madisetti, Universities Press.
- Handbook of Modern Sensors, Jacob Fraden, Springer.
- Instrument Engineers' Handbook: Process Control, B.G. Liptak, CRC Press
- Hands-On Machine Learning with Scikit-Learn, Keras & TensorFlow, A. Géron, O'Reilly
- Microsystem Design, S.D. Senturia, Springer
- Microelectromechanical Systems Engineering, N. Maluf and K. Williams, Artech House
- Process Control Instrumentation Technology, Curtis D. Johnson, Pearson Education
- Deep Learning, I. Goodfellow, Y. Bengio, and A. Courville, MIT Press
- *Computational Fluid Dynamics: The Basics with Applications*,John D. Anderson, McGraw-Hill (selected topics).

Learning Outcomes (LOs)

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

- **LO1:** Explain the principles of MEMS, smart sensors, and nanomaterial-based sensing technologies.
- **LO2:** Describe biomedical instrumentation, biopotential measurements, and advanced signal conditioning techniques.
- **LO3:** Analyze industrial instrumentation systems, process control, and data acquisition techniques.

- **LO4:** Explain the architecture and applications of IoT-enabled instrumentation and connected sensing systems.
- **LO5:** Apply basic machine learning concepts for the analysis of sensor and experimental data.
- **LO6:** Describe digital twins, simulation tools, quantum sensing, and emerging trends in intelligent instrumentation.

Discipline Specific Elective

Course Type: Discipline Specific Elective
Paper Title: High Energy Physics - II
Paper code: PPYC DSE IID
Credits: 4 (Theory)
Marks Distribution: 70 (End-Semester) + 30 (In-Semester) = 100 (Total)
Total Contact Hours: 60

Course Objectives
Upon successful completion of this course, a student will be able to:
- **Formulate** and apply the principles of quantum field theory across various physical systems.
- **Apply** the advanced concepts of quantum field theory specifically to quantum electrodynamics (QED).
- **Explain** the underlying physics of fundamental particles and their corresponding gauge interactions.

Unit I: Quantum Field Theory (25 Lectures | 29 Marks)
Concept of field and quantization, Lagrangian of a field, Schwinger's action principle. Fock space states and their eigenvalues, method of second quantization. Canonical quantization of scalar, vector, and spinor fields. Energy, momentum, and charge of the field. The concept of the vacuum in field theory and propagators. Charge conjugation (C), Parity (P), and Time reversal (T) transformation properties of scalar and vector fields.
Unit II: Quantum Electrodynamics (20 Lectures | 23 Marks)
S-matrix, covariant perturbation theory, and path integral formalism. Feynman diagrams (rules in momentum space) and Wick's theorem. Calculation of second-order processes: electron interaction with an electromagnetic field, Mott scattering, Compton scattering (Klein-Nishina formula), Møller scattering, Bhabha scattering, and bremsstrahlung. Introduction to vacuum polarization and the self-energy of the electron.
Unit III: Particle Interactions (15 Lectures | 18 Marks)
Fundamental interactions (electromagnetic, weak, strong, and gravitational) and their characteristics. Conservation laws and decay modes. Charged leptonic weak interactions, decays of the muon, neutron, and charged pions. Neutral weak interactions and the Fermi theory of weak interaction. V-A interaction theory, Cabibbo angles, and weak mixing angles. CP violation and the CPT theorem.

Mode of Assessment
Total Marks: 100

1. In-Semester Assessment (30 Marks)

- **Written Test:** 20 Marks
- **Continuous Assessment:** 10 Marks (Assignments, Presentations, Attendance, Classroom Interaction, and Quizzes)

2. End-Semester Examination (70 Marks)

- Comprehensive written examination covering all three units.

Expected Learning Outcomes

After the completion of this course, it is expected that the student will:

- Develop a rigorous mathematical and conceptual understanding of field quantization and creation/annihilation operators.
- Master the techniques of covariant perturbation theory and Feynman diagrams to compute scattering cross-sections and decay rates in QED.
- Gain a deep theoretical understanding of weak interactions, parity violation, and the fundamental conservation laws governing the Standard Model.

Suggested Readings

1. **Introduction to Elementary Particles**, D. J. Griffiths (John Wiley & Sons).
2. **Quarks and Leptons**, Francis Halzen and Alan D. Martin (John Wiley & Sons).
3. **Introduction to High Energy Physics**, Donald H. Perkins (Cambridge University Press).
4. **Gauge Theory of Elementary Particle Physics**, T. P. Cheng and L. F. Li (Oxford University Press).
5. **Physics of Elementary Particles**, H. Muirhead (Pergamon Press).
6. **Quantum Field Theory**, Lewis H. Ryder (Cambridge University Press).
7. **An Introduction to Quantum Field Theory**, M. E. Peskin and D. V. Schroeder (Levant Books/Westview Press).
8. **Field Quantization**, W. Greiner and J. Reinhardt (Springer).
9. **A First Book of Quantum Field Theory**, A. Lahiri and P. B. Pal (Narosa).

Minor Papers

Semester-I

Paper Name: Solid State Physics and Electronics (minor)
Paper Code: PPYN 101
Credit: 4

Course Objectives

At the completion of the course, a student will be able to:

1. Understand the basics of crystals and X-Ray crystallography and Reciprocal lattice concepts.
2. Band theory and its use to distinguish among conductors, insulators and semiconductors.
3. To learn about superconductivity and related topics.
4. Semiconductors and Transistors and their characteristics.
5. Introductory idea of Digital electronics, Boolean algebra, Gates and about IC's.

Unit-I: Crystal Structure

[6 Marks | 5 Lectures]

Solids: Amorphous and Crystalline Materials. Lattice Translation Vectors. Lattice with a Basis, Unit Cell, Miller Indices, Types of Lattices, Diffraction of X-rays by Crystals, Bragg's Law. Concept of Reciprocal Lattice and Brillouin Zone.

Unit-II: Elementary Band Theory

[12 Marks | 10 Lectures]

Free electron theory and its limitations, Kronig Penny model, Band Gap, Conductor, Semiconductor and insulator. Conductivity of Semiconductor, mobility, Hall Effect. Measurement of conductivity (04 probe method) & Hall coefficient.

Unit-III: Superconductivity

[5 Marks | 5 Lectures]

Critical Temperature. Critical magnetic field. Meissner effect. Type I and type II Superconductors, London's Equation and Penetration Depth. Isotope effect. Idea of BCS theory (No derivation).

Unit-IV: Semiconductor Devices

[23 Marks | 20 Lectures]

- **Semiconductor Basics:** P and N type semiconductors. Energy Level Diagram. Conductivity and Mobility, Concept of Drift velocity, Barrier Formation in PN Junction Diode. Static and Dynamic Resistance. Current Flow Mechanism in Forward and Reverse Biased Diode, Current Flow Mechanism in Forward and Reverse Biased Diode.
- **Two-terminal Devices and their Applications:** (1) Rectifier Diode: Half-wave Rectifiers. Centre-tapped and Bridge Full-wave Rectifiers, Calculation of Ripple Factor and Rectification Efficiency, C-filter.
- (2) Zener Diode and Voltage Regulation.
- (3) Tunneling Diode.
- **Transistors:** n-p-n and p-n-p Transistors. Characteristics of CB, CE and CC Configurations. Current gains α and β, Relations between α and β.

Unit-V: Digital Circuits

[24 Marks | 20 Lectures]

- **Logic Gates & Number Systems:** Difference between Analog and Digital Circuits. Binary Numbers. Decimal to Binary and Binary to Decimal Conversion. BCD, Octal and Hexadecimal numbers. AND, OR and NOT Gates (realization using Diodes and Transistor). NAND and NOR Gates as Universal Gates. XOR and XNOR Gates.
- **Boolean Algebra:** De Morgan's Theorems. Boolean Laws. Simplification of Logic Circuit using Boolean Algebra. Fundamental Products. Idea of Minterms and Maxterms. Conversion of a Truth table into Equivalent Logic Circuit by (1) Sum of Products Method and (2) Karnaugh Map.

- **Integrated Circuits (ICs):** Active & Passive components. Discrete components. Wafer. Chip. Advantages and drawbacks of ICs. Scale of integration: SSI, MSI, LSI and VLSI (basic idea and definitions only). Classification of ICs. Examples of Linear and Digital ICs.

Recommended Readings

- *Introduction to Solid State Physics*, Charles Kittel, 8th Edition, 2004, Wiley India Pvt. Ltd
- *Solid State Physics*, M.A. Wahab, 2011, Narosa Publications
- *Elementary Solid-State Physics*, 1/e M. Ali Omar, 1999, Pearson India
- *Elements of Solid-State Physics*, J.P. Srivastava, 4th Edition, 2015, Prentice-Hall of India
- *Solid State Electronic Devices*, B.G. Streetman & S.K. Banerjee, 6th Edn., 2009, PHI Learning
- *Electronic Devices & Circuits*, S. Salivahanan & N.S. Kumar, 3rd Ed., 2012, Tata Mc-Graw Hill
- *Semiconductor Devices: Physics and Technology*, S.M. Sze, 2nd Ed., 2002, Wiley India
- *Fundamentals of Digital Circuits*, Anand Kumar, 2nd Edn, 2009, PHI Learning Pvt. Ltd.
- *Digital Circuits and Systems*, Venugopal, 2011, Tata McGraw Hill.
- *Digital Electronics*, G K Kharate, 2010, Oxford University Press

Expected Learner Outcome

The course will enable the students to get some basic ideas of Solid State Physics and Electronics, in the first part, the physics of Condensed Matter Physics, where X-Ray Crystallography, Band Theory, Hall Effect and Super conductivity are incorporated and in the later part the students may expect to learn all about Semi conducting devices like Diodes, Transistors and its uses as Amplifiers etc and IC's.

Semester-II

Paper Name: Lab-II (minor)

Paper Code: PPYN-201

Credit: 4

Course Objective

This is a Lab paper, so a student may be expected to learn some underlying physical phenomena by hands-on experience in the fields of Waves and Optics (Group A), in the field of modern physics (Group B) and in electronics (Group C).

Group-A: Wave and Optics

2. To investigate the motion of coupled oscillators.
3. To determine the Frequency of an Electrically Maintained Tuning Fork by Melde's Experiment and to verify λ^2– T Law.
4. To study Lissajous Figures.
5. Familiarization with Schuster`s focussing; determination of angle of prism.
6. To determine the Coefficient of Viscosity of water by Capillary Flow Method (Poiseuille's method).
7. To determine the Refractive Index of the Material of a Prism using Sodium Light.
8. To determine Dispersive Power of the Material of a Prism using Mercury Light.
9. To determine the value of Cauchy Constants.
10. To determine the Resolving Power of a Prism.
11. To determine wavelength of sodium light using Fresnel Biprism.
12. To determine wavelength of sodium light using Newton's Rings.
13. To determine the wavelength of Laser light using Diffraction/Interference of Single Slit.
14. To determine wavelength of (1) Sodium and (2) Spectral lines of the Mercury light using plane diffraction Grating.
15. To determine the Resolving Power of a Plane Diffraction Grating.
16. To measure the intensity using photosensor and laser in diffraction patterns of single and double slits.

Group-B: Elements of Modern Physics

1. Measurement of Planck's constant using black body radiation and photo-detector.
2. Photo-electric effect: photo current versus intensity and wavelength of light; maximum energy of photoelectrons versus frequency of light.
3. To determine the Planck's constant using LEDs of at least 4 different colours.
4. To determine the value of e/m by (a) Magnetic focusing or (b) Bar magnet.
5. To setup the Millikan oil drop apparatus and determine the charge of an electron.
6. To show the tunneling effect in tunnel diode using I-V characteristics.
7. To determine the wavelength of laser source using diffraction of single slit.
8. To determine the wavelength of laser source using diffraction of double slits.
9. To determine (1) wavelength and (2) angular spread of He-Ne laser using plane diffraction grating.

Group-C: Electronics

1. To study V-I characteristics of PN junction diode, and Light emitting diode.
2. To study the V-I characteristics of a Zener diode and its use as voltage regulator.
3. To study the characteristics of a Bipolar Junction Transistor in CE configuration.
4. To study the frequency response of voltage gain of a RC-coupled transistor amplifier.
5. To verify and design AND, OR, NOT and XOR gates using NAND gates.
6. To design a combinational logic system for a specified Truth Table.
7. To convert a Boolean expression into logic circuit and design it using logic gate IC.

Recommended Readings

- *Advanced Practical Physics for students*, B.L. Flint and H.T. Worsnop, 1971, Asia Publishing House.
- *Advanced level Physics Practicals*, Michael Nelson and Jon M. Ogborn, 4th Edition, reprinted 1985, Heinemann Educational Publishers.
- *A Text Book of Practical Physics*, I. Prakash & Ramakrishna, 11th Ed., 2011, KitabMahal
- *Elements of Solid-State Physics*, J.P. Srivastava, 2nd Ed., 2006, Prentice-Hall of India.
- *Modern Digital Electronics*, R.P. Jain, 4th Edition, 2010, Tata McGraw Hill.

Expected Learner Outcome

After performing a good number of practical of this paper the student will acquire a sound experimental knowledge in the fields of Sound and Optics, in Quantum Physics and LASER and also in the fields of both analog and digital electronics.