

M.Sc. Physics Syllabus

Programme Outcomes (POs)

PO1. Advanced Scientific Knowledge: Demonstrate a comprehensive and in-depth understanding of fundamental and advanced concepts, principles, and theories across core and specialized areas of Physics.

PO2. Analytical and Problem-Solving Abilities: Identify, formulate, and analyze complex physical problems using appropriate mathematical, computational, and logical approaches to arrive at substantiated conclusions.

PO3. Research and Investigation: Design and conduct scientific investigations, experimental setup, data acquisition, analysis, and interpretation, with an understanding of research methodology.

PO4. Technical and Instrumentational Proficiency: Acquire and apply technical skills to operate modern equipment, sophisticated software, and advanced instrumentation for modeling, and measurement in physics.

PO5. Collaborative and Multidisciplinary Work: Function effectively as an individual, and as a member or leader in diverse teams, in multidisciplinary settings.

PO6. Effective Communication: Communicate complex scientific information clearly and effectively, through structured reports, presentations, and digital media, to both specialized and general audiences.

PO7. Ethics and Professional Integrity: Understand and commit to professional ethics and responsibilities, including academic integrity, objectivity, and social accountability in all scientific endeavors.

PO8. Lifelong Course and Adaptability: Recognize the need for, and engage in, independent and lifelong Course to adapt to the evolving landscape of scientific and technological advancements.

PO9. Societal and Environmental Context: Assess the societal, environmental, and economic impact of scientific developments and technological applications, with an awareness of sustainable practices.

PO10. Project Management and Scholarship: Demonstrate knowledge and application of scientific principles and project management skills to plan and execute research projects, managing time and resources efficiently.

Programme Specific Outcomes (PSOs)

PSO1. Foundational Mastery: Articulate and apply the fundamental principles of Classical and Quantum Mechanics, Electrodynamics, and Statistical Physics to explain diverse physical phenomena.

PSO2. Mathematical Formulation: Employ advanced mathematical methods and techniques to model physical systems, formulate problems, and develop quantitative descriptions.

PSO3. Specialized Expertise: Acquire specialized knowledge in key domains of modern physics such as Condensed Matter Physics, Nuclear & Particle Physics, and Electronics, and integrate concepts to solve interdisciplinary problems.

PSO4. Experimental and Computational Proficiency: Gain hands-on experience with modern experimental techniques, computational tools, and data analysis methods for the investigation of physical systems.

PSO5. Research Aptitude: Develop the capability to undertake scientific research, critically evaluate scientific literature, and contribute to the advancement of knowledge in a chosen area of physics.

M.Sc. PHYSICS COURSE DETAILS

SEMESTER-I

Sr. No	Course Code	Course Title	Course Type	L	T	P	Cr
1	PHY501	Mathematical Physics	C	4	1	0	4
2	PHY502	Classical Mechanics	C	4	1	0	4
3	PHY503	Electromagnetic Theory	C	4	1	0	4
4	PHY504	Quantum Mechanics - I	C	4	1	0	4
5	PHY531	Practical-I	SB	0	0	10	5
6	PHY532	Practical-II	SB	0	0	10	5
Total Credits							26

SEMESTER-II

Sr. No	Course Code	Course Title	Course Type	L	T	P	Cr
1	PHY505	Quantum Mechanics - II	C	3	1	0	4

Sr. No	Course Code	Course Title	Course Type	L	T	P	Cr
2	PHY506	Statistical Mechanics	C	3	1	0	4
3	PHY507	Solid State Electronics	C	3	1	0	4
4	PHY508	Atomic & Molecular Physics	C	3	1	0	4
5	PHY533	Practical-III	SB	0	0	10	5
6	PHY534	Practical-IV	SB	0	0	10	5
Total Credits							26

SEMESTER-III

CORE COURSES

Sr. No	Course Code	Course Title	Course Type	L	T	P	C r
1	PHY601	Condensed Matter Physics	C	3	1	0	4
2	PHY602	Nuclear Physics	C	3	1	0	4

SPECIALIZATION PAPERS (Choose one stream)

CONDENSED MATTER PHYSICS

- | 1 | PHY651 | Condensed Matter Physics - I | DE | 3 | 1 | 0 | 4 |
- | 2 | PHY652 | Condensed Matter Physics - II | DE | 3 | 1 | 0 | 4 |
- | 3 | PHY631 | Practical-I: Condensed Matter Physics | SB | 0 | 0 | 10 | 5 |
- | 4 | PHY631 | Practical-II: Condensed Matter Physics | SB | 0 | 0 | 10 | 5 |

ELECTRONICS

- | 1 | PHY653 | Analog and Digital Electronics | DE | 3 | 1 | 0 | 4 |
- | 2 | PHY654 | Microwaves | DE | 3 | 1 | 0 | 4 |
- | 3 | PHY632 | Practical-I: Electronics | SB | 0 | 0 | 10 | 5 |
- | 4 | PHY632 | Practical-II: Electronics | SB | 0 | 0 | 10 | 5 |

LASER AND SPECTROSCOPY

- | 1 | PHY655 | Laser Spectroscopy | DE | 3 | 1 | 0 | 4 |
- | 2 | PHY656 | Electronic Spectra of Diatomic Molecules | DE | 3 | 1 | 0 | 4 |
- | 3 | PHY633 | Practical-I: Laser & Spectroscopy | SB | 0 | 0 | 10 | 5 |
- | 4 | PHY633 | Practical-II: Laser & Spectroscopy | SB | 0 | 0 | 10 | 5 |

NON-LINEAR OPTICS

1	PHY657	Coherence Theory & Elementary Nonlinear Optics	DE	3	1	0	4
2	PHY658	Quantum States of Radiation	DE	3	1	0	4
3	PHY634	Practical-I: Non-Linear Optics	SB	0	0	10	5
4	PHY634	Practical-II: Non-Linear Optics	SB	0	0	10	5

X-RAY AND ION BEAM

1	PHY659	X-Ray Physics and Instrumentation	DE	3	1	0	4
2	PHY660	Beam Physics and Instrumentation	DE	3	1	0	4
3	PHY635	Practical-I: X-rays & Ion Beam	SB	0	0	10	5
4	PHY635	Practical-II: X-rays & Ion Beam	SB	0	0	10	5

NUCLEAR AND PARTICLE PHYSICS

1	PHY661	Advanced Nuclear & Particle Physics - I	DE	3	1	0	4
2	PHY662	Advanced Nuclear & Particle Physics - II	DE	3	1	0	4
3	PHY636	Practical-I: Nuclear & Particle Physics	SB	0	0	10	5
4	PHY636	Practical-II: Nuclear & Particle Physics	SB	0	0	10	5

Total Credits for Semester III: 26

SEMESTER-IV

CORE COURSES

Sr. No	Course Code	Course Title	Course Type	L	T	P	Cr
1	PHY603	Experimental Techniques & Control Systems	C	3	1	0	4

ELECTIVE PAPERS (Choose any one)

1	PHY663	Programming for Numerical Methods	DE	3	1	0	4
2	PHY664	Electrodynamics and Second Quantization	DE	3	1	0	4
3	PHY665	Group Theory	DE	3	1	0	4

SPECIALIZATION CONTINUATION (Continue from Semester III stream)

CONDENSED MATTER PHYSICS

1	PHY666	Condensed Matter Physics - I	DE	3	1	0	4
2	PHY667	Condensed Matter Physics - II	DE	3	1	0	4
3	PHY631	Practical-I: Condensed Matter Physics	SB	0	0	10	5
4	PHY637	Practical-II: Condensed Matter Physics	SB	0	0	10	5

ELECTRONICS

1	PHY668	Microprocessor	DE	3	1	0	4
2	PHY669	Semiconductor Devices	DE	3	1	0	4
3	PHY632	Practical-I: Electronics	SB	0	0	10	5
4	PHY638	Practical-II: Electronics	SB	0	0	10	5

LASER AND SPECTROSCOPY

1	PHY670	Advanced Atomic Spectroscopy	DE	3	1	0	4
2	PHY671	IR & Raman Spectra of Polyatomic Molecules	DE	3	1	0	4
3	PHY633	Practical-I: Laser & Spectroscopy	SB	0	0	10	5
4	PHY639	Practical-II: Laser & Spectroscopy	SB	0	0	10	5

NON-LINEAR OPTICS

1	PHY674	Resonant Interaction of Atoms with Radiation - I	DE	3	1	0	4
2	PHY675	Resonant Interaction of Atoms with Radiation - II	DE	3	1	0	4
3	PHY635	Practical-I: Non-Linear Optics	SB	0	0	10	5
4	PHY641	Practical-II: Non-Linear Optics	SB	0	0	10	5

X-RAY AND ION BEAM

1	PHY672	Geometrical X-Ray Diffraction	DE	3	1	0	4
2	PHY673	Ion Beams Induced Modification & Characterization	DE	3	1	0	4
3	PHY634	Practical-I: X-rays & Ion Beam	SB	0	0	10	5
4	PHY640	Practical-II: X-rays & Ion Beam	SB	0	0	10	5

NUCLEAR AND PARTICLE PHYSICS

1	PHY676	Advanced Nuclear & Particle Physics - I	DE	3	1	0	4
2	PHY677	Advanced Nuclear & Particle Physics - II	DE	3	1	0	4
3	PHY636	Practical-I: Nuclear & Particle Physics	SB	0	0	10	5
4	PHY642	Practical-II: Nuclear & Particle Physics	SB	0	0	10	5

Total Credits for Semester IV: 26

CREDIT SUMMARY

Semester	Credits
Semester I	26
Semester II	26
Semester III	26
Semester IV	26
Total Credits	104

Abbreviations:

L: Lecture, **T:** Tutorial, **P:** Practical, **Cr:** Credits

C: Core, **DE:** Discipline Elective, **SB:** Skill-based

Evaluation Pattern: The assessment and evaluation of students shall adhere to the Choice Based Credit System (CBCS) regulations of the University of Allahabad. Students' performance in all courses shall be evaluated through two components: continuous assessment and end-term examination. Continuous assessment, which constitutes 40% of the overall marks assign to a particular course, may include tests, assignments, projects, presentations, and fieldwork, depending on the course requirements. The end-term examination shall account for the remaining 60% of the marks, in line with university norms. This evaluation pattern also applies to internship, practicum, and dissertation courses. However, for these courses (internship/ dissertation/ filed work) the end-term examination will involve seminar presentations, viva-voce, and other modalities as determined by the external/internal Board of Examiners appointed by the Board of Studies (BoS) of the department. This comprehensive assessment approach ensures a balanced evaluation of students' academic performance, integrating both theoretical understanding and practical application.

The evaluation of non-credit Value-added course shall be done in 100 marks completely internal continuous assessment decided by the respective course instructor, for satisfactory completion students has to secure at least 40% marks.

Continuous Assessment of 40% weightage: For the theory courses the continuous assessment shall be done in 40 marks, which include:

End-term Examination of 60% weightage: The end-term examination of all courses shall be done in 60 marks. The question paper of all the *theory courses shall be of 60 marks consisting 4 questions with internal choices as per university norm. The duration of the examination shall be of 3 hours.*

Any changes in assessment pattern shall be subjected to changes in Choice Based Credit System (CBCS) regulation of the university.

SEMESTER – I

L T P Cr

3 1 0 4

Course Title: Mathematical Physics

Course Code: PHY501

Total Hours: 45

Course Objectives

- To equip students with the knowledge of complex analysis, including Cauchy's theorem and residue calculus, for evaluating complex integrals.
- To enable students to solve and classify linear differential equations using series expansion methods and other analytical techniques.
- To provide a thorough understanding of special functions (Bessel, Legendre, Hermite, Laguerre) and their properties for application in physical problems.
- To familiarize students with integral transform methods (Laplace and Fourier) for solving differential equations encountered in physics.
- To introduce the concepts of the Dirac delta function and Green's functions for solving boundary value problems like Poisson's and the wave equation.

Course Outcomes

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

CO1. Demonstrate understanding of complex functions and their properties through Cauchy's theorem, Laurent series, and the residue method for evaluating integrals.

CO2. Solve linear differential equations and classify singular points using appropriate analytical techniques.

CO3. Explain and apply properties of special functions such as Bessel, Legendre, Hermite, and Laguerre equations in physical contexts.

CO4. Apply integral transform methods including Laplace and Fourier transforms to solve mathematical and physical problems.

CO5. Understand the Dirac delta function and Green's function for solving Laplace, Poisson, and inhomogeneous wave equations.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	1	3	1	2	2	1					1
CO2	2	3	1	2	1	3	1	2	3	1					1
CO3	2	3	1	2	1	3	1	2	2	1					1
CO4	2	3	1	2	1	3	1	2	3	1					1
CO5	2	3	1	2	1	3	1	2	3	1					1

- 1 = High Mapping
2 = Moderate Mapping
3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Complex Analysis: Analytic functions, Cauchy–Riemann equations, Cauchy’s theorem, Cauchy’s integral formula, Laurent series, Poles and Residue theorem. Evaluation of definite integrals using the residue method.	CO1
II / 9 hrs	Linear Differential Equations: Second-order linear differential equations; regular, regular singular and singular points; series expansion method and its applications.	CO2
III / 9 hrs	Special Functions: Bessel, Legendre, Hermite, and Laguerre differential equations—derivations, recurrence relations, generating functions, and orthogonality properties.	CO3
IV / 9 hrs	Integral Transforms: Laplace transforms, Fourier theorem, Fourier series, Fourier transforms and their applications to the solution of ordinary differential equations.	CO4
V / 9 hrs	Dirac Delta and Green’s Functions: Dirac delta function; Green’s function for Laplace operator; solutions of Poisson’s and inhomogeneous wave equations and their physical applications.	CO5

Suggested Readings

1. Arfken, G., Weber, H., & Harris, F. (2012). *Mathematical Methods for Physicists*. Elsevier Academic Press, USA.
2. Kreyszig, E. (2011). *Advanced Engineering Mathematics*. Wiley India Pvt. Ltd., New Delhi.
3. Pipes, L. A. (1985). *Applied Mathematics for Engineers and Physicists*. McGraw-Hill, Noida.
4. Zill, D. G. (2012). *Advanced Engineering Mathematics*. Jones & Bartlett Course, USA.

L T P Cr

3 1 0 4

Course Title: Classical Mechanics

Course Code: PHY502

Total Hours: 45

Course Objectives

- To establish a deep understanding of variational principles and Lagrange's formalism for deriving equations of motion and identifying symmetries.
- To enable students to formulate and solve mechanical problems using the Hamiltonian formalism and identify conserved quantities.
- To introduce the concepts of canonical transformations and Poisson brackets for simplifying and analyzing dynamical systems.
- To connect classical mechanics with wave optics and quantum mechanics through the Hamilton-Jacobi theory.
- To provide the tools to analyze small oscillations, determine normal modes, and describe classical fields using Lagrangian and Hamiltonian densities.

Course Outcomes

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

CO1. Explain the principles of variational calculus and derive Lagrange's equations using Hamilton's principle; apply conservation theorems to identify symmetry properties in physical systems.

CO2. Formulate and analyze the Hamiltonian formalism through Legendre transformations and Hamilton's equations of motion; identify and use cyclic coordinates in dynamical problems.

CO3. Understand and apply canonical transformations and Poisson brackets to simplify and solve mechanical systems.

CO4. Apply the Hamilton–Jacobi theory to connect the principles of classical mechanics with geometrical optics and wave mechanics.

CO5. Analyze small oscillations about equilibrium, determine normal modes and their frequencies, and formulate the Lagrangian and Hamiltonian descriptions of classical fields.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	2	1	2	1	3	1	2	3	1					1
CO2	3	3	1	2	1	3	1	2	3	1					1
CO3	3	3	1	2	1	3	1	2	3	1					1
CO4	3	3	1	3	2	3	1	2	3	1					1
CO5	3	2	1	3	1	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Variational Principles and Lagrange's Equations: Hamilton's principle, calculus of variations, derivation of Lagrange's equations, conservation theorems, and symmetry properties.	CO1
II / 9 hrs	Hamiltonian Formalism: Legendre transformations, formulation of Hamilton's equations of motion, identification of cyclic coordinates and conserved quantities.	CO2
III / 9 hrs	Canonical Transformations: Concept and formulation of canonical transformations; generating functions; Poisson brackets and their properties; invariance of Poisson brackets.	CO3
IV / 9 hrs	Hamilton–Jacobi Theory: Hamilton–Jacobi equations, Hamilton–Jacobi method, applications to geometrical optics and connection to wave mechanics.	CO4
V / 9 hrs	Small Oscillations and Normal Modes: Oscillations about stable equilibrium, normal coordinates and normal mode analysis, frequencies of small oscillations; Lagrangian and Hamiltonian formalism for classical fields.	CO5

Suggested Readings

1. Goldstein, H., Poole, C., & Safko, J. (2011). *Classical Mechanics* (3rd ed.). Pearson Education, India.
2. Marion, J. B., & Thornton, S. T. (2008). *Classical Dynamics of Particles and Systems* (5th ed.). Cengage Course.
3. Landau, L. D., & Lifshitz, E. M. (1976). *Mechanics* (Vol. 1). Pergamon Press.
4. Rana, N. C., & Joag, P. S. (2011). *Classical Mechanics*. Tata McGraw-Hill Education.

SEMESTER – I

L T P Cr

3 1 0 4

Course Title: Electromagnetic Theory

Course Code: PHY503

Total Hours: 45

Course Objectives

- To help students understand the propagation and confinement of electromagnetic waves in guided structures like transmission lines and waveguides.
- To provide a working knowledge of tensor analysis for application in advanced physical theories, including electrodynamics.
- To develop a rigorous understanding of the geometry of space-time in special relativity and the properties of Lorentz transformations.
- To enable students to formulate Maxwell's equations in a manifestly covariant form using four-vectors and field tensors.
- To analyze the electromagnetic fields produced by moving charges and the covariant formulation of the Lorentz force law.

Course Outcomes

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

CO1. Understand the propagation of guided electromagnetic waves in transmission lines, waveguides, and cavity resonators.

CO2. Apply the concepts of tensor analysis including coordinate transformations, covariant and contravariant components, metric tensors, and index operations.

CO3. Explain the geometry of space-time in special relativity and analyze Lorentz transformations, invariance of the Minkowski metric, and properties of Lorentz groups.

CO4. Formulate Maxwell's equations in covariant form using four-vectors and field tensors, and derive invariants of the electromagnetic field.

CO5. Analyze the electromagnetic fields and forces associated with moving charges and describe the covariant form of Lorentz force law and particle dynamics in uniform fields.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	2	1	3	1	3	1	2	3	1					1
CO2	2	3	1	2	1	3	1	2	3	1					1
CO3	3	3	1	3	2	3	1	2	3	1					1
CO4	3	3	1	3	2	3	1	2	3	1					1
CO5	3	3	1	3	2	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Guided Electromagnetic Waves: Transmission lines and waveguides; modes in rectangular waveguides; cutoff frequency; phase and group velocities; cavity resonators and their properties.	CO1
II / 9 hrs	Tensor Analysis: Coordinate transformations; contravariant, covariant, and mixed tensors; metric tensor; raising and lowering of indices; contraction of indices; physical significance in electrodynamics.	CO2
III / 9 hrs	Minkowski Space and Lorentz Transformations: Geometry of space-time in special relativity; Minkowski metric; light cone and causality; invariance of the Minkowski metric; Lorentz group – proper, improper, and orthochronous transformations; pseudo-tensors.	CO3
IV / 9 hrs	Covariant Formulation of Electromagnetism: Charge-current density four-vector; scalar and vector potentials; gauge invariance; electromagnetic potential four-vector; electromagnetic field tensor; Lorentz transformation of electric and magnetic fields; field invariants.	CO4
V / 9 hrs	Electromagnetic Fields of Moving Charges: Field of a charge moving with constant velocity; covariant form of Lorentz force law; motion of charged particles in static and uniform electric and magnetic fields.	CO5

Suggested Readings

1. Griffiths, D. J. (2017). *Introduction to Electrodynamics* (4th ed.). Cambridge University Press.
2. Jackson, J. D. (1999). *Classical Electrodynamics* (3rd ed.). Wiley.
3. Panofsky, W. K. H., & Phillips, M. (2005). *Classical Electricity and Magnetism* (2nd ed.). Dover Publications.
4. Reitz, J. R., Milford, F. J., & Christy, R. W. (2008). *Foundations of Electromagnetic Theory* (4th ed.). Addison-Wesley.
5. Landau, L. D., & Lifshitz, E. M. (1975). *The Classical Theory of Fields* (Vol. 2). Pergamon Press.

SEMESTER – I

L	T	P	Cr
3	1	0	4

Course Title: Quantum Mechanics – I

Course Code: PHY504

Total Hours: 45

Course Objectives

- To introduce Dirac's bra-ket notation and the abstract Hilbert space structure for a powerful and general formulation of quantum mechanics.
- To develop proficiency in various representations of quantum mechanics (Schrödinger, Heisenberg, Dirac) and the matrix formulation.
- To provide a comprehensive understanding of angular momentum algebra for both orbital and spin angular momentum.
- To enable students to handle coupled angular momentum systems using Clebsch-Gordan coefficients and apply them to problems like fine-structure.
- To introduce the formalism of second quantization for the treatment of quantum fields and many-particle systems.

Course Outcomes

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

CO1. Understand and apply Dirac's bra-ket formalism, Hilbert space structure, and operator representation of observables in quantum mechanics.

CO2. Analyze quantum mechanical systems using matrix formulations, uncertainty relations, and various representations such as Schrödinger, Heisenberg, and Dirac pictures.

CO3. Comprehend the formalism of orbital and spin angular momentum and perform operations using angular momentum algebra.

CO4. Evaluate coupled angular momentum systems using Clebsch-Gordon coefficients and apply them to central field problems, including spin-orbit coupling and fine-structure calculations.

CO5. Apply second quantization formalism to field theory, derive Lagrangian equations for fields, and utilize creation and annihilation operators for quantized field analysis.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	3	3	1	2	3	1					1

CO2	2	3	1	2	3	3	1	2	3	1					1
CO3	2	3	1	2	3	3	1	2	3	1					1
CO4	2	3	1	3	3	3	1	2	3	1					1
CO5	2	3	1	3	3	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	Dirac's Formalism and Quantum States: Bra-ket notation; Hilbert space and vector representation of states; projection operators; observables as operators; orthonormality and completeness; relation between ket and wave functions; coordinate and momentum representations.	CO1
II / 9 hrs	Matrix Formulation and Quantum Representations: Matrix theory of the harmonic oscillator; uncertainty relations; Schrödinger, Heisenberg, and Dirac representations of quantum mechanics.	CO2
III / 9 hrs	Angular Momentum in Quantum Mechanics: Orbital angular momentum; commutation relations and angular momentum algebra; spin angular momentum; addition of angular momenta.	CO3
IV / 9 hrs	Coupling Schemes and Fine-Structure: Clebsch-Gordon coefficients; addition of angular momentum $\frac{1}{2}$ with $\frac{1}{2}$ and 1; spherical harmonics in central field problems; spin-orbit coupling; fine-structure of atomic levels.	CO4
V / 9 hrs	Second Quantization and Quantum Fields: Non-covariant derivation of Lagrangian equations for fields; canonically conjugate momentum density	CO5

Units/Hours	Contents	Mapping with Course Course Outcome
	for Schrödinger field; quantum conditions from commutation relations; annihilation and creation operators; second quantization based on commutation and anti-commutation relations; examples using operator algebra.	

Suggested Readings

1. Cohen-Tannoudji, C., Diu, B., & Laloe, F. (2005). *Quantum Mechanics* (Vols. I & II). Wiley-VCH.
2. Sakurai, J. J., & Napolitano, J. (2017). *Modern Quantum Mechanics* (2nd ed.). Cambridge University Press.
3. Schiff, L. I. (1968). *Quantum Mechanics* (3rd ed.). McGraw-Hill.
4. Dirac, P. A. M. (1958). *The Principles of Quantum Mechanics* (4th ed.). Oxford University Press.
5. Zettili, N. (2009). *Quantum Mechanics: Concepts and Applications* (2nd ed.). Wiley.

SEMESTER – II

L	T	P	Cr
3	1	0	4

Course Title: Quantum Mechanics – II

Course Code: PHY505

Total Hours: 45

Course Objectives

- To equip students with approximation methods like time-independent perturbation theory, variational method, and WKB for solving realistic quantum problems.
- To enable students to analyze time-dependent phenomena, including transitions, radiation, and scattering, using time-dependent perturbation theory.
- To provide a thorough understanding of scattering theory, including partial wave analysis and the Born approximation.
- To introduce the concepts of relativistic quantum mechanics through the Klein-Gordon and Dirac equations.
- To interpret the physical implications of the Dirac equation, including negative energy states, hole theory, and the role of spin.

Course Outcomes

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

CO1. Apply time-independent perturbation theory, variational principles, and the WKB approximation to solve quantum mechanical problems.

CO2. Employ time-dependent perturbation theory to analyze transition probabilities, radiative processes, and scattering phenomena.

CO3. Explain and apply the methods of partial waves, phase-shift analysis, and Born approximation in scattering theory.

CO4. Understand relativistic quantum mechanics through the formulation and interpretation of the Klein–Gordon and Dirac equations.

CO5. Interpret the physical implications of negative energy states, hole theory, and the role of spin and position operators in relativistic particle dynamics.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	3	3	1	2	3	1					1
CO2	2	3	1	3	3	3	1	2	3	1					1
CO3	2	3	1	3	3	3	1	2	3	1					1

CO4	2	3	1	3	3	3	1	2	3	1					1
CO5	2	3	1	3	3	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Approximation Methods: Time-independent perturbation theory and its applications; variational method and energy minimization; WKB approximation and connection formulas.	CO1
II / 9 hrs	Time-Dependent Perturbation Theory and Radiation: Transition probabilities; constant and harmonic perturbations; Fermi's Golden Rule; semi-classical theory of radiation; Einstein A and B coefficients; selection rules; introduction to quantum scattering.	CO2
III / 9 hrs	Scattering Theory: Method of partial waves; phase-shift analysis; Born approximation and its validity; applications to simple scattering problems.	CO3
IV / 9 hrs	Relativistic Wave Equations – I: Klein–Gordon equation for a free particle and its solution; introduction to Dirac equation, Dirac matrices, and bilinear covariants; covariance of Dirac equation.	CO4
V / 9 hrs	Relativistic Wave Equations – II: Solutions of Dirac equation for a free particle; negative energy states and hole theory; interpretation of spin; position operator in Dirac theory.	CO5

Suggested Readings

1. Sakurai, J. J., & Napolitano, J. (2017). *Modern Quantum Mechanics* (2nd ed.). Cambridge University Press.

2. Schiff, L. I. (1968). *Quantum Mechanics* (3rd ed.). McGraw-Hill.
3. Bjorken, J. D., & Drell, S. D. (1964). *Relativistic Quantum Mechanics*. McGraw-Hill.
4. Greiner, W. (1990). *Quantum Mechanics: An Introduction*. Springer-Verlag.
5. Zettili, N. (2009). *Quantum Mechanics: Concepts and Applications* (2nd ed.). Wiley.
6. Cohen-Tannoudji, C., Diu, B., & Laloe, F. (2005). *Quantum Mechanics* (Vols. I & II). Wiley-VCH.

SEMESTER – II

L	T	P	Cr
3	1	0	4

Course Title: Statistical Mechanics

Course Code: PHY506

Total Hours: 45

Course Objectives

- To deepen the understanding of Gibbs ensembles and enable the calculation of partition functions for various physical systems.
- To explain the principles of quantum statistics (Bose-Einstein and Fermi-Dirac) and their macroscopic consequences like Bose-Einstein condensation.
- To analyze the properties of degenerate Fermi gases and understand fluctuations in different statistical ensembles.
- To introduce the concepts of random and Markov processes, and establish the connection between fluctuations and dissipation.
- To provide the tools to solve problems involving stochastic dynamics, including the Fokker-Planck equation and Brownian motion.

Course Outcomes

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

CO1. Apply the concepts of Gibbs ensembles and calculate partition functions for different physical systems such as gases and harmonic oscillators.

CO2. Explain and analyze Bose–Einstein and Fermi–Dirac statistics in the grand canonical ensemble and interpret quantum phenomena like Bose–Einstein condensation and superfluidity.

CO3. Examine the properties of degenerate Fermi gases and study fluctuations in various ensembles using probabilistic models.

CO4. Understand random and Markov processes, Langevin dynamics, and correlation functions; relate them through the fluctuation–dissipation theorem and Nyquist theorem.

CO5. Solve problems involving conditional probabilities, Fokker–Planck equation, and Brownian motion in statistical and stochastic systems.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	3	3	1	2	3	1					1
CO2	2	3	1	3	3	3	1	2	3	1					1
CO3	2	3	1	3	3	3	1	2	3	1					1
CO4	2	3	1	3	3	3	1	2	3	1					1
CO5	2	3	1	3	3	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	Gibbs Ensembles and Partition Functions: Review of ensembles; partition function for perfect gas and ensemble of harmonic oscillators; partition functions for monoatomic, diatomic, and polyatomic gases; introduction to grand partition function.	CO1
II / 9 hrs	Quantum Statistics and Bose Systems: Grand potential; Fermi–Dirac and Bose–Einstein distributions; degenerate Bose gas; momentum condensation; properties of liquid He II; two-fluid model; superfluidity.	CO2
III / 9 hrs	Fermi Systems and Fluctuations: Degenerate Fermi gas; conduction electrons in metals; energy and concentration fluctuations in canonical and grand canonical ensembles; one-dimensional random walk; Gaussian distribution.	CO3
IV / 9 hrs	Random Processes and Fluctuation Theorems: Random and Markov processes; Langevin equation; correlation	CO4

Units/Hours	Contents	Mapping with Course Course Outcome
	functions; fluctuation–dissipation theorem; Wiener–Khinchin theorem; Nyquist theorem and noise spectra.	
V / 9 hrs	Stochastic Dynamics: Conditional probability; derivation and applications of Fokker–Planck equation; Brownian motion and diffusion phenomena.	CO5

Suggested Readings

1. Pathria, R. K., & Beale, P. D. (2011). *Statistical Mechanics* (3rd ed.). Elsevier Academic Press.
2. Reif, F. (2008). *Fundamentals of Statistical and Thermal Physics*. Waveland Press.
3. Huang, K. (1987). *Statistical Mechanics*. Wiley Eastern Ltd.
4. Landau, L. D., & Lifshitz, E. M. (1980). *Statistical Physics, Part I* (Vol. 5). Pergamon Press.
5. Tolman, R. C. (1938). *The Principles of Statistical Mechanics*. Oxford University Press.

SEMESTER – II

L	T	P	Cr
3	1	0	4

Course Title: Solid State Electronics

Course Code: PHY507

Total Hours: 45

Course Objectives

- To enable students to explain the operation of fundamental semiconductor devices (diodes, transistors) and analyze their behavior in circuits.
- To understand the working principles of Field-Effect Transistors (FETs) and the frequency response of multistage amplifiers.
- To analyze feedback amplifiers and oscillator circuits, including their stability and frequency characteristics.
- To describe the operation and analyze the performance of power amplifiers and RF amplifiers.

- To explain the principles of various modulation and demodulation techniques used in communication systems.

Course Outcomes

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

CO1. Explain the operation and characteristics of semiconductor devices such as diodes and transistors, and analyze their behavior in rectifier and amplifier circuits.

CO2. Understand the working principles of field-effect transistors (FETs), multistage amplifiers, and their high-frequency response.

CO3. Analyze different types of feedback amplifiers and oscillators, and evaluate their frequency stability using Nyquist criteria.

CO4. Describe the operation of power and RF amplifiers, including large-signal, push-pull, and tuned amplifiers.

CO5. Explain the principles of modulation and demodulation techniques and the working of FM detectors and discriminators.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	3	3	1	2	3	1					1
CO2	2	3	1	3	3	3	1	2	3	1					1
CO3	2	3	1	3	3	3	1	2	3	1					1
CO4	2	3	1	3	3	3	1	2	3	1					1
CO5	2	3	1	3	3	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	P–N Junction and Bipolar Devices: P–N junction diode; rectifier with LC filter; electronic voltage regulator; BJT h-parameter model, interconversion in CE, CB, and CC configurations; low-frequency transistor amplifier; thermal stability and bias stabilization.	CO1

Units/Hours	Contents	Mapping with Course Course Outcome
II / 9 hrs	Field Effect and Multistage Amplifiers: FET operation and small-signal models; dynamic parameters; CS and CD amplifiers; multistage amplifiers; BJT at high frequencies; frequency response of gain and phase shift in RC-coupled amplifiers.	CO2
III / 9 hrs	Feedback and Oscillator Circuits: Negative feedback amplifiers; gain stability and Nyquist stability criterion; sinusoidal oscillators—phase shift, Wien's bridge, and crystal oscillators; astable multivibrator circuits.	CO3
IV / 9 hrs	Power and RF Amplifiers: Large-signal amplifier and distortion analysis; push-pull amplifier configuration; single and double tuned amplifiers; bandwidth and resonance considerations.	CO4
V / 9 hrs	Modulation and Demodulation Techniques: Frequency and phase modulation; frequency modulation demodulation; frequency conversion and tracking; AGC (Automatic Gain Control), AFC (Automatic Frequency Control), FM detection, amplitude limiter, phase discriminator, ratio detector.	CO5

Suggested Readings

1. Millman, J., & Halkias, C. C. (2008). *Integrated Electronics: Analog and Digital Circuits and Systems*. McGraw-Hill.
2. Boylestad, R. L., & Nashelsky, L. (2015). *Electronic Devices and Circuit Theory* (11th ed.). Pearson Education.
3. Malvino, A. P., & Leach, D. P. (2010). *Digital Principles and Applications*. McGraw-Hill.
4. Sedra, A. S., & Smith, K. C. (2010). *Microelectronic Circuits* (6th ed.). Oxford University Press.
5. Millman, J., & Taub, H. (1991). *Pulse, Digital and Switching Waveforms*. McGraw-Hill.

SEMESTER – II

L	T	P	Cr
3	1	0	4

Course Title: Atomic & Molecular Physics

Course Code: PHY508

Total Hours: 45

Course Objectives

- To explain the quantum states of electrons in atoms and interpret the spectra of hydrogen, helium, and alkali atoms.
- To describe the structure and splitting of spectral lines, X-ray spectra, and various coupling schemes.
- To analyze the effects of external electric and magnetic fields on atomic spectra and understand the principles of ESR and NMR.
- To interpret the rotational and vibrational spectra of diatomic molecules using quantum mechanical models.
- To explain Raman and electronic spectra of molecules, including the Franck-Condon principle.

Course Outcomes

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

CO1. Explain the quantum states of electrons in atoms and interpret the spectra of hydrogen, helium, and alkali atoms using fine-structure principles.

CO2. Describe the width and splitting of spectral lines, X-ray spectra, and coupling schemes such as LS and JJ coupling, along with hyperfine structure.

CO3. Analyze the effects of external magnetic and electric fields on atomic spectra and understand the principles of ESR and NMR spectroscopy.

CO4. Interpret the rotational and vibrational spectra of diatomic molecules using quantum mechanical models and identify isotopic effects.

CO5. Explain Raman and electronic spectra, including vibrational structure, fine-structure of bands, and the Franck–Condon principle governing intensity distributions.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	2	3	3	1	2	3	1					1
CO2	2	3	1	3	3	3	1	2	3	1					1
CO3	2	3	1	3	3	3	1	2	3	1					1

CO4	2	3	1	3	3	3	1	2	3	1					1
CO5	2	3	1	3	3	3	1	2	3	1					1

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Atomic Spectra and Quantum States: Quantum states of an electron in an atom; spectra of hydrogen and helium atoms; fine structure of alkali atoms; energy level diagrams; Sharp, Principal, Diffuse, and Fundamental series.	CO1
II / 9 hrs	Spectral Line Structure and Couplings: Width of spectral lines; X-ray spectroscopy; spectroscopic terms; LS and JJ coupling; hyperfine structure and its origin.	CO2
III / 9 hrs	Effects of Fields and Resonance Techniques: Zeeman effect; Paschen–Back effect; Stark effect; principles and applications of electron spin resonance (ESR) and nuclear magnetic resonance (NMR); chemical shift and relaxation mechanisms.	CO3
IV / 9 hrs	Molecular Spectra – I: Rotational spectra of diatomic molecules (rigid and non-rigid rotator models); vibrational spectra (harmonic and anharmonic oscillators); symmetric top molecules; vibrating rotator; isotopic shift in spectra.	CO4
V / 9 hrs	Molecular Spectra – II: Raman spectra (quantum mechanical and classical treatments); electronic spectra—vibrational structure and fine structure of band systems; intensity distribution and Franck–Condon principle.	CO5

Suggested Readings

1. Banwell, C. N., & McCash, E. M. (2013). *Fundamentals of Molecular Spectroscopy* (5th ed.). McGraw-Hill.

2. Herzberg, G. (1944). *Atomic Spectra and Atomic Structure*. Dover Publications.
3. Herzberg, G. (1950). *Molecular Spectra and Molecular Structure* (Vols. I–III). Van Nostrand Reinhold.
4. White, H. E. (1951). *Introduction to Atomic Spectra*. McGraw-Hill.
5. Foot, C. J. (2005). *Atomic Physics*. Oxford University Press.

SEMESTER – III

L	T	P	Cr
3	1	0	4

Course Title: Condensed Matter Physics

Course Code: PHY601

Total Hours: 45

Course Objectives

- To explain the fundamental band theories of solids and experimental methods for investigating the Fermi surface.
- To understand the phenomenological and microscopic (BCS) theory of superconductivity, including the Josephson effect.
- To describe the dielectric properties of ionic lattices and introduce the physics of ordered phases like quasicrystals.
- To identify different types of lattice defects and understand their influence on material properties.
- To discuss the quantum origins of diamagnetism, paramagnetism, and ferromagnetism, and their temperature dependence.

Course Outcomes

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

CO1. Explain the fundamental band theories of solids and methods for investigating the Fermi surface.

CO2. Understand the basic concepts of superconductivity, BCS theory, energy gap measurement techniques, and Josephson effects.

CO3. Describe the dielectric properties of ionic lattices, phonon modes, and the physics of ordered phases such as quasicrystals and conducting polymers.

CO4. Identify different types of lattice defects, their characteristics, and their influence on material properties.

CO5. Discuss the origin and temperature dependence of various magnetic phenomena such as diamagnetism, paramagnetism, and ferromagnetism.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	1	3	2	3	1	2	3	1					1
CO2	3	3	1	3	2	3	1	2	3	1					1

CO3	3	2	1	3	2	3	1	2	3	1					1
CO4	3	2	1	3	1	3	1	2	3	1					1
CO5	3	3	1	3	2	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours Contents Mapping with Course Course Outcome

I / 9 hrs **Electron Band Theory:** One-electron band theories; plane-wave and localized wave functions; nearly free electron approximation; elementary discussion of Orthogonalized Plane Wave (OPW) and Pseudopotential methods; variation of Fermi energy in extrinsic semiconductors; de Haas–van Alphen effect for investigating the Fermi surface. CO1

II / 9 hrs **Superconductivity:** Meissner and isotope effects; Type I and II superconductors; Cooper pairs; basic ideas of BCS theory; estimation of transition temperature; superconducting energy gap and its measurement by infrared absorption and electron tunneling; Josephson effect; introduction to high-temperature superconductors. CO2

III / 9 hrs **Lattice Dynamics and Ordered Phases:** Ionic lattice in an infrared field; dielectric constant; Lyddane–Sachs–Teller (L.S.T.) relation; longitudinal (LO) and transverse (TO) phonon modes; ordered phases—translational and orientational order; quasicrystals and conducting polymers. CO3

IV / 9 hrs **Lattice Defects:** Point defects—Frenkel and Schottky types; color centers; equilibrium concentration of vacancies; line defects—edge and screw dislocations; Burgers vector and its significance. CO4

V / 9 hrs **Magnetic Properties of Solids:** Diamagnetism and Langevin theory; quantum theory of paramagnetism—rare-earth and transition metal ions; ferromagnetism, Curie temperature, Heisenberg exchange model; temperature dependence of saturation magnetization. CO5

Suggested Readings

Kittel, C. (2005). Introduction to Solid State Physics (8th ed.). Wiley.

Ashcroft, N. W., & Mermin, N. D. (1976). Solid State Physics. Saunders College.

Dekker, A. J. (2012). Solid State Physics. Macmillan.

Mott, N. F., & Jones, H. (1958). The Theory of the Properties of Metals and Alloys. Oxford University Press.

Tinkham, M. (1996). Introduction to Superconductivity (2nd ed.). Dover Publications.

L T P Cr

3 1 0 4

Course Title: Nuclear Physics

Course Code: PHY602

Total Hours: 45

Course Objectives

- To understand the properties of nuclear forces through the study of the deuteron and nucleon-nucleon scattering.
- To explain the nuclear shell model and collective models for describing nuclear structure and moments.
- To analyze different nuclear reaction mechanisms, including compound nucleus formation and direct reactions.
- To classify elementary particles based on their properties and interactions, and explain the quark model.
- To describe the mechanisms and characteristics of alpha, beta, and gamma decay processes.

Course Outcomes

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

CO1. Understand the properties of nuclear forces through studies of deuteron structure and nucleon–nucleon scattering experiments.

CO2. Explain the nuclear shell model, single-particle motion, and nuclear moments, and describe collective nuclear behavior qualitatively.

CO3. Analyze nuclear reaction mechanisms, including compound nucleus formation, resonance phenomena, and heavy ion reactions.

CO4. Classify elementary particles based on fundamental interactions, quantum numbers, and conservation laws, and explain the quark model and SU(3) symmetry.

CO5. Describe the mechanisms and characteristics of alpha, beta, and gamma decay processes.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	1	3	3	3	1	2	3	1					1
CO2	3	3	1	3	3	3	1	2	3	1					1
CO3	3	3	1	3	3	3	1	2	3	1					1
CO4	3	3	1	3	3	3	1	2	3	1					1

CO5	3	3	1	3	3	3	1	2	3	1					1
-----	---	---	---	---	---	---	---	---	---	---	--	--	--	--	---

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Nuclear Forces and Scattering: Deuteron structure; nucleon–nucleon interactions; n–n, n–p, and p–p scattering; charge independence and charge symmetry of nuclear forces.	CO1
II / 9 hrs	Nuclear Models: Shell model; extreme single-particle model; angular momentum coupling schemes; magnetic and quadrupole moments of nuclei; nuclear isomerism; qualitative introduction to the collective model.	CO2
III / 9 hrs	Nuclear Reactions: Compound nucleus formation and Breit–Wigner formula; direct reaction mechanisms; heavy-ion reactions; relativistic kinematics and reaction Q-values.	CO3
IV / 9 hrs	Elementary Particles and Interactions: Fundamental interactions; classification of elementary particles; isospin and strangeness; conservation laws and symmetries (C, CP, CPT); SU(3) symmetry and the quark model.	CO4
V / 9 hrs	Radioactive Decays: Mechanisms and characteristics of alpha, beta, and gamma decay; decay probabilities, energy spectra, and selection rules.	CO5

Suggested Readings

1. Krane, K. S. (1988). *Introductory Nuclear Physics*. Wiley.
2. Segre, E. (1980). *Nuclei and Particles: An Introduction to Nuclear and Subnuclear Physics*. Benjamin-Cummings.
3. Satchler, G. R. (1990). *Introduction to Nuclear Reactions*. Oxford University Press.
4. Perkins, D. H. (2000). *Introduction to High Energy Physics* (4th ed.). Cambridge University Press.
5. Evans, R. D. (1955). *The Atomic Nucleus*. McGraw-Hill.

CONDENSED MATTER PHYSICS

Course Title: Condensed Matter Physics

Course Code: PHY651

Total Hours: 45

Course Objectives

- To apply Ewald's method for lattice sums and understand the concept of the Lorentz field in dielectric crystals.
- To develop the general theory of lattice vibrations in non-primitive lattices and describe atomic motion in terms of normal coordinates.
- To explain the concept of phonons and analyze their behavior in ionic crystals.
- To quantize lattice vibrations and apply the shell model to describe the vibrational properties of ionic crystals.
- To understand experimental techniques like inelastic neutron scattering and analytical methods like Kramers-Kronig relations for studying condensed matter systems.

Course Outcomes

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

CO1. Apply Ewald's method to compute lattice sums and understand the concept of the Lorentz field in crystalline materials.

CO2. Develop an understanding of lattice dynamics in non-primitive lattices and describe the motion of atoms in terms of normal coordinates.

CO3. Explain the concept of phonons and analyze their behavior in ionic crystals.

CO4. Quantize lattice vibrations and apply the shell model to describe vibrational properties of solids.

CO5. Understand the techniques of inelastic neutron scattering for studying phonons and use the Kramers-Kronig relations in condensed matter analysis.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	1	3	2	3	1	2	3	1					1
CO2	3	3	1	3	2	3	1	2	3	1					1
CO3	3	3	1	3	3	3	1	2	3	1					1
CO4	3	3	1	3	3	3	1	2	3	1					1
CO5	3	3	1	3	2	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours Contents		Mapping with Course Outcome
I / 9 hrs	Electrostatics in Crystals: Ewald's summation method for lattice sums; Lorentz field in dielectric crystals; macroscopic and microscopic electric fields.	CO1
II / 9 hrs	Lattice Dynamics: General theory of lattice vibrations in non-primitive lattices; equations of motion; normal coordinate formulation and dispersion relations.	CO2
III / 9 hrs	Phonon Concept: Definition and properties of phonons; phonon dispersion in ionic crystals; acoustic and optical modes; specific heat of solids and Debye approximation.	CO3
IV / 9 hrs	Quantization and Shell Model: Quantization of lattice vibrations; second quantization formalism; shell model of ionic crystals and its applications.	CO4
V / 9 hrs	Experimental and Analytical Methods: Inelastic scattering of slow neutrons by crystals for phonon studies; Kramers–Kronig relations and their use in optical and dielectric response analysis.	CO5

Suggested Readings

1. Kittel, C. (2005). *Introduction to Solid State Physics* (8th ed.). Wiley.
2. Ashcroft, N. W., & Mermin, N. D. (1976). *Solid State Physics*. Saunders College.
3. Dekker, A. J. (2012). *Solid State Physics*. Macmillan.
4. Born, M., & Huang, K. (1954). *Dynamical Theory of Crystal Lattices*. Oxford University Press.
5. Srivastava, G. P. (1990). *The Physics of Phonons*. Taylor & Francis.

L	T	P	Cr
3	1	0	4

Course Title: Condensed Matter Physics

Course Code: PHY652

Total Hours: 45

Course Objectives

- To enable students to explain the dielectric properties and polarizability of ionic crystals, and to understand the fundamental principles of first and second-order Raman scattering processes.

- To describe how Raman scattering is used to study phonons and to analyze the interactions of electromagnetic waves with collective excitations like plasmons and polaritons.
- To introduce the concept and mathematical formulation of both classical and quantum Green's functions for studying excitations in physical systems.
- To develop the ability to apply static Green's function techniques and Fourier transforms to analyze problems in lattice dynamics and electronic structure.
- To analyze the effects of point defects and impurities on the vibrational and electronic states in crystals, including the formation of localized, gap, and resonance modes.

Course Outcomes

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

CO1. Explain the dielectric properties and polarizability of ionic crystals and understand Raman scattering processes.

CO2. Describe phonon studies using Raman scattering and the interactions of electromagnetic waves with plasmons and polaritons.

CO3. Understand the concept and application of classical and quantum Green's functions in the study of excitations in imperfect crystals.

CO4. Apply static Green's function and Fourier transform techniques to analyze lattice vibrations and electron energy states.

CO5. Analyze the effects of point defects and impurities in crystals and their influence on localized, gap, and resonance states.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	1	3	2	3	1	2	3	1					1
CO2	3	3	1	3	3	3	1	2	3	1					1
CO3	3	3	1	3	3	3	1	2	3	1					1
CO4	3	3	1	3	3	3	1	2	3	1					1
CO5	3	3	1	3	3	3	1	2	3	1					1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course	Course Outcome
-------------	----------	---------------------	----------------

I / 9 hrs	Polarization and Raman Scattering: Dielectric constant of ionic crystals; static and dynamic polarizability; polarizability in variable fields; Placzek's approximation; first-order and second-order Raman scattering processes.		CO1
II / 9 hrs	Phonons and Electromagnetic Interactions: Elementary ideas of phonon studies via Raman scattering; plasmons and their dispersion; interaction of electromagnetic waves with phonons; polaritons and their characteristics.		CO2
III / 9 hrs	Excitations and Green's Functions: Definition of classical Green's functions; application to one-dimensional harmonic oscillator; principle of causality; double-time quantum Green's functions; correlation functions and spectral density.		CO3
IV / 9 hrs	Applications of Static Green's Functions: Fourier transform of static Green's function; applications to lattice vibrations; electron energy states in crystalline solids.		CO4
V / 9 hrs	Defects and Impurity States: Point defects in one-dimensional lattices; localized, gap, and resonance modes; extension to impurity electron energy states; gap states and their implications.		CO5

Suggested Readings

Kittel, C. (2005). Introduction to Solid State Physics (8th ed.). Wiley.

Ashcroft, N. W., & Mermin, N. D. (1976). Solid State Physics. Saunders College.

Born, M., & Huang, K. (1954). Dynamical Theory of Crystal Lattices. Oxford University Press.

Srivastava, G. P. (1990). The Physics of Phonons. Taylor & Francis.

Mahan, G. D. (2000). Many-Particle Physics (3rd ed.). Springer.

Ziman, J. M. (1972). Principles of the Theory of Solids. Cambridge University Press.

ELECTRONICS

L	T	P	Cr
3	1	0	4

Course Title: Analog and Digital Electronics

Course Code: PHY653

Total Hours: 45

Course Objectives

- To analyze the high-frequency behavior of BJTs and design wide-band amplifiers with appropriate frequency compensation.
- To understand the working principles of operational amplifiers and differential amplifiers, including methods for offset balancing.

- To apply operational amplifiers to design linear analog systems like filters, converters, and mathematical operation circuits.
- To design and analyze nonlinear analog circuits including comparators, sample-and-hold circuits, and waveform generators.
- To explain the working of digital logic families, flip-flops, registers, and counters used in sequential logic systems.

Course Outcomes

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

CO1. Analyze the high-frequency behavior of BJTs, derive transient responses using Laplace transforms, and design wide-band amplifiers with frequency compensation.

CO2. Understand the working principles of operational amplifiers, differential amplifiers, and methods for offset balancing and temperature compensation.

CO3. Apply operational amplifiers to design linear analog systems such as filters, amplifiers, converters, and mathematical operation circuits.

CO4. Design and analyze nonlinear analog circuits including comparators, sample-and-hold, converters, and waveform generators.

CO5. Explain the working of digital circuits including logic families, flip-flops, registers, and counters used in sequential logic systems.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	2	3	1	3	1	3	1	3	3	2	1	1			1
CO2	2	2	1	3	1	3	1	3	3	2	1	1			1
CO3	2	3	1	3	1	3	1	3	3	2	1	1			1
CO4	2	3	1	3	1	3	1	3	3	2	1	1			1
CO5	2	2	1	3	1	3	1	3	3	2	1	1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours Contents Mapping with Course Course Outcome

I / 9 hrs **Wide-Band Amplifiers:** Review of BJT operation at high frequencies; hybrid- π equivalent model; junction capacitance; base spreading resistance; Laplace transform

method for RC amplifier (CE configuration); transient response; effect of emitter bypass capacitor; low- and high-frequency compensation techniques. CO1

II / 9 hrs **Operational Amplifiers:** Ideal op-amp model; emitter-coupled differential amplifier; common-mode rejection ratio (CMRR); constant current source operation; emitter follower, level translation, and output stages; offset voltage and current, balancing circuits, temperature drift, and measurement of op-amp parameters. CO2

III / 9 hrs **Linear Analog Systems:** Basic op-amp applications— inverter, scale changer, phase shifter, adder, voltage-to-current and current-to-voltage converters, voltage follower, differential and bridge amplifiers; analog integration and differentiation; analog compensation; solving simultaneous and differential equations; amplitude and time scaling; active filters—Butterworth and resonant band-pass filters. CO3

IV / 9 hrs **Nonlinear Analog Systems:** Comparators; sample-and-hold circuits; AC/DC converters and detectors; logarithmic and antilogarithmic amplifiers; log multipliers; waveform generators; regenerative comparators. CO4

V / 9 hrs **Digital Electronics (TTL-Based):** Review of combinational logic circuits; flip-flops—DSR, JK, master–slave types; registers and counters—shift registers, ripple counters, up–down asynchronous and synchronous counters, ring counters, and sequence generators. CO5

Suggested Readings

Millman, J., & Halkias, C. C. (2008). Integrated Electronics: Analog and Digital Circuits and Systems. McGraw-Hill.

Boylestad, R. L., & Nashelsky, L. (2015). Electronic Devices and Circuit Theory (11th ed.). Pearson Education.

Malvino, A. P., & Leach, D. P. (2010). Digital Principles and Applications. McGraw-Hill.

Sedra, A. S., & Smith, K. C. (2010). Microelectronic Circuits (6th ed.). Oxford University Press.

Floyd, T. L. (2013). Digital Fundamentals (11th ed.). Pearson Education.

Gayakwad, R. A. (2011). Op-Amps and Linear Integrated Circuits (4th ed.). Pearson.

L T P Cr

3 1 0 4

Course Title: Microwaves

Course Code: PHY654

Total Hours: 45

Course Objectives

- To analyze the propagation characteristics of various waveguides, including cylindrical and two-conductor systems, and to evaluate network parameters like reflection coefficient, standing wave ratio (SWR), and scattering coefficients.

- To explain the operating principles, structures, and applications of key microwave components such as directional couplers, hybrid tees, cavity resonators, and non-reciprocal ferrite devices (gyrators, isolators).
- To describe the fundamental mechanisms of velocity and density modulation in vacuum tube devices and to analyze the performance of klystrons and reflex klystrons as microwave amplifiers and oscillators.
- To explain the working principles, electron dynamics, and operational characteristics of magnetrons, Travelling Wave Tubes (TWTs), and Backward Wave Oscillators (BWOs) for microwave and millimeter-wave generation.
- To develop practical skills in performing and interpreting standard microwave measurements—including power, frequency, VSWR, impedance, and dielectric properties—using modern instrumentation like network analyzers.

Course Outcomes

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

CO1. Understand the propagation characteristics of cylindrical and two-conductor waveguides, and analyze reflection, standing wave ratio, and scattering in microwave networks.

CO2. Explain the structure and working of key microwave components such as directional couplers, hybrid Tees, cavity resonators, and ferrite devices including gyrators and isolators.

CO3. Describe the principles of velocity and density modulation in vacuum tube microwave generators such as klystrons and reflex klystrons, and analyze their performance parameters.

CO4. Explain the working principles of magnetrons, travelling wave tubes (TWTs), and backward wave oscillators (BWOs), and understand their role in millimeter-wave generation.

CO5. Perform and interpret microwave measurements of power, frequency, VSWR, impedance, and dielectric properties using modern measurement systems.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	1	3	1	3	1	3	3	2	1	1			1
CO2	2	2	1	3	1	3	1	3	3	2	1	1			1
CO3	2	3	1	3	1	3	1	3	3	2	1	1			1
CO4	2	3	1	3	1	3	1	3	3	2	1	1			1
CO5	2	2	1	3	1	3	1	3	3	2	1	1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours Contents	Mapping with Course Course Outcome
I / 9 hrs Waveguides and Microwave Components: Cylindrical waveguides, two-conductor systems and TEM mode; discontinuity, reflection coefficient, and SWR; scattering coefficients of multiple junctions; directional coupler, hybrid Tee; cylindrical cavity resonator—solutions and oscillation modes; wave meter, attenuator, slotted line; magnetic properties of ferrites; Faraday rotation; gyrator and isolator; microwave integrated circuits (MICs).	CO1, CO2
II / 9 hrs Vacuum Tube Microwave Generators (Klystrons): Principles of velocity and density modulation; small-signal theory of bunching; two-cavity klystron amplifier and multiplier; two-cavity klystron oscillator; reflex klystron—bunching theory, optimum power, effect of repeller voltage, electronic admittance, efficiency, and electronic tuning.	CO3
III / 9 hrs Magnetron Oscillators: Construction and working of magnetrons; travelling wave magnetron; modes of oscillation; electron dynamics; output power and frequency characteristics.	CO4
IV / 9 hrs Travelling Wave Devices: Structure and operation of TWT; electron beam dynamics; beam and slow-wave structure coupling; waves in periodic structures; TWT amplifier and backward wave oscillator (BWO); generation of millimeter waves.	CO4
V / 9 hrs Microwave Measurements: Measurement of power, frequency, VSWR, impedance, dielectric permittivity; use of network analyzer; determination of scattering coefficients; experimental setups and calibration.	CO5

Suggested Readings

1. Liao, S. Y. (2011). *Microwave Devices and Circuits* (3rd ed.). Pearson Education.
2. Pozar, D. M. (2012). *Microwave Engineering* (4th ed.). Wiley.
3. Collin, R. E. (1992). *Foundations for Microwave Engineering* (2nd ed.). Wiley-IEEE Press.
4. Das, A., & Das, S. K. (2015). *Microwave Engineering*. McGraw-Hill Education.
5. Annapurna Das & Sisir K. Das. (2008). *Microwave Engineering*. Tata McGraw-Hill.
6. Gupta, K. C., & Amarjit Singh. (2003). *Microwave Integrated Circuits*. Wiley Eastern Ltd.

LASER AND SPECTROSCOPY

L T P Cr

3 1 0 4

Course Title: Laser Spectroscopy

Course Code: PHY655

Total Hours: 45

Course Objectives

- To explain different types of light sources and detectors used in spectroscopic investigations.
- To understand the principles, design, and operation of various fixed-frequency and tunable laser systems.
- To describe laser-based spectroscopic techniques like photoacoustic, optogalvanic, and laser-induced fluorescence spectroscopy.
- To explain advanced Raman and nonlinear spectroscopic techniques (CARS, SRS, SERS) and time-resolved spectroscopy.
- To apply laser spectroscopy in practical applications such as Fourier transform spectroscopy, isotope separation, and medical diagnostics.

Course Outcomes

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

CO1. Explain different types of light sources, detectors, and optical detection systems used in laser spectroscopy.

CO2. Understand the principles, design, and operation of fixed-frequency and tunable lasers, including solid-state, gas, excimer, dye, and semiconductor lasers.

CO3. Describe laser-based spectroscopic techniques such as laser photoacoustic, optogalvanic, and laser-induced fluorescence spectroscopy.

CO4. Explain advanced Raman and nonlinear optical spectroscopy techniques including CARS, SRS, and SERS, and understand time-resolved spectroscopy.

CO5. Apply laser spectroscopy in practical applications such as Fourier transform spectroscopy, isotope separation, and medical diagnostics and treatment.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	2	1	3	2	3	1	3	3	2	1	1			1
CO2	3	2	1	3	3	3	1	3	3	2	1	1			1

CO3	3	2	1	3	3	3	1	3	3	2	1	1			1
CO4	3	3	1	3	3	3	1	3	3	2	1	1			1
CO5	3	3	1	3	2	3	1	3	3	2	1	1	2		1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Light Sources and Detectors: Arc, spark, discharge, and beam-foil light sources; synchrotron radiation; laser as a light source; thermal and direct photo detectors; optical multichannel analyzer (OMA); charge-coupled devices (CCD) and intensified CCD (ICCD).	CO1
II / 9 hrs	Laser Systems: Fixed-frequency and tunable lasers; working principles and characteristics of Nd:YAG laser, Argon-ion laser, Excimer laser, Dye laser, and Semiconductor laser systems.	CO2
III / 9 hrs	Laser-based Spectroscopic Techniques – I: Laser photoacoustic spectroscopy; laser-induced fluorescence (LIF); laser optogalvanic spectroscopy—principles, instrumentation, and applications.	CO3
IV / 9 hrs	Laser-based Spectroscopic Techniques – II: Laser Raman spectroscopy—CARS (Coherent Anti-Stokes Raman Scattering), SRS (Stimulated Raman Scattering), and SERS (Surface Enhanced Raman Scattering); time-resolved spectroscopy.	CO4
V / 9 hrs	Applications of Laser Spectroscopy: Fourier transform spectroscopy; laser isotope separation techniques; applications of lasers in medicine—diagnostic and therapeutic uses.	CO5

Suggested Readings

1. Demtröder, W. (2014). *Laser Spectroscopy: Basic Concepts and Instrumentation* (4th ed.). Springer.
2. Svanberg, S. (2004). *Atomic and Molecular Spectroscopy: Basic Aspects and Practical Applications* (4th ed.). Springer.
3. Siegman, A. E. (1986). *Lasers*. University Science Books.
4. Letokhov, V. S. (1987). *Laser Photoionization Spectroscopy*. Academic Press.

5. Maiman, T. H. (1960). *Laser Fundamentals and Applications*. Springer.
6. Duarte, F. J. (2008). *Tunable Laser Applications* (2nd ed.). CRC Press.

L T P Cr

3 1 0 4

Course Title: Electronic Spectra of Diatomic Molecules

Course Code: PHY656

Total Hours: 45

Course Objectives

- To establish a foundational understanding of the features of electronic spectra and to enable students to apply the Franck-Condon principle for interpreting vibrational intensity distributions in molecular transitions.
- To analyze the influence of thermal population distributions on spectral intensities and to understand the role of nuclear spin in determining the fine-structure of molecular bands.
- To classify diatomic molecules into their respective molecular states, explain multiplet structures, and apply the governing selection rules for electronic transitions.
- To construct electronic configurations for diatomic molecules using the building-up principle and molecular orbital theory, including the interpretation of bonding, antibonding, and energy-level diagrams.
- To describe the origins of continuous and diffuse molecular spectra and to determine molecular dissociation energies by analyzing spectroscopic data and potential energy curves.

Course Outcomes

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

CO1. Recall and explain the basic features of electronic spectra of diatomic molecules and apply the Franck–Condon principle to interpret molecular transitions.

CO2. Understand thermal population distribution among quantum states and analyze how nuclear spin affects fine-structure intensities in molecular spectra.

CO3. Classify molecular states, understand multiplet structures, and apply selection rules for electronic transitions.

CO4. Construct electronic configurations for diatomic molecules using molecular orbital theory and building-up principles.

CO5. Describe continuous and diffuse spectra and determine molecular dissociation energies from spectroscopic data.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	2	1	3	3	3	1	2	3	1		1			1
CO2	3	3	3	3	3	3	1	2	3	1		1			1
CO3	3	2	1	3	3	3	1	2	3	1		1			1
CO4	3	3	1	3	3	3	1	2	3	1		1			1
CO5	3	3	1	3	3	3	1	2	3	1		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	Introduction to Electronic Spectra: Review of electronic spectra of diatomic molecules; Deslandres table; Franck–Condon principle and its application to molecular transitions and intensity distributions.	CO1
II / 9 hrs	Thermal and Spin Effects: Thermal distribution of quantum states; intensity of molecular bands in electronic spectra; effect of nuclear spin on fine-structure intensities.	CO2
III / 9 hrs	Molecular States and Selection Rules: Classification of molecular states; multiplet structure; coupling and uncoupling phenomena; selection rules governing electronic transitions in diatomic molecules.	CO3
IV / 9 hrs	Molecular Structure and Configuration: Building-up principles; electronic configurations of diatomic molecules; molecular orbital theory—bonding, antibonding, and energy-level diagrams.	CO4
V / 9 hrs	Continuous and Diffuse Spectra: Basic concepts of continuous and diffuse molecular spectra; determination of heats of dissociation using spectroscopic data and potential energy curves.	CO5

Suggested Readings

1. Herzberg, G. (1950). *Molecular Spectra and Molecular Structure: Spectra of Diatomic Molecules* (Vol. I). Van Nostrand Reinhold.

2. Banwell, C. N., & McCash, E. M. (2013). *Fundamentals of Molecular Spectroscopy* (5th ed.). McGraw-Hill.
3. Herzberg, G. (1945). *Atomic Spectra and Atomic Structure*. Dover Publications.
4. Hollas, J. M. (2004). *Modern Spectroscopy* (4th ed.). Wiley.
5. Bernath, P. F. (2005). *Spectra of Atoms and Molecules* (2nd ed.). Oxford University Press.

NON-LINEAR OPTICS

L T P Cr

3 1 0 4

Course Title: Coherence Theory and Elementary Nonlinear Optics

Course Code: PHY657

Total Hours: 45

Course Objectives

- To explain the mathematical representation of polychromatic light and analyze coherence functions and spectral correlations.
- To apply the Van Cittert-Zernike theorem to evaluate the coherence properties of thermal sources.
- To describe the interaction of free electrons with electromagnetic waves and elementary concepts of harmonic generation.
- To understand nonlinear polarization, the classical anharmonic oscillator model, and phenomena like self-focusing.
- To explain basic nonlinear optical effects such as the Kerr effect and harmonic generation, including the concept of phase matching.

Course Outcomes

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

CO1. Explain the mathematical representation of polychromatic light using analytic signals and analyze coherence functions and spectral correlations.

CO2. Apply the Van Cittert–Zernike theorem to evaluate spatial and temporal coherence properties of thermal sources.

CO3. Describe the interaction of free electrons with electromagnetic waves and discuss drift acceleration and second harmonic generation processes.

CO4. Understand nonlinear polarization, the classical anharmonic oscillator model, and phenomena such as self-focusing and self-steepening.

CO5. Explain basic nonlinear optical effects such as the Kerr effect and harmonic generation in dielectrics, including the concept of phase matching.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1			1
CO2	3	3	2	3	3	3	1	2	3	1		1			1
CO3	3	3	1	3	3	3	1	2	3	1		1			1
CO4	3	3	1	3	3	3	1	2	3	1		1			1
CO5	3	3	1	3	3	3	1	2	3	1		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Coherence and Correlation: Representation of polychromatic fields by analytic signals; mutual and self-coherence functions; degree of coherence; relationship between spectral profile and correlation functions.	CO1
II / 9 hrs	Coherence of Thermal Sources: Van Cittert–Zernike theorem and its applications; degree of coherence for circular thermal sources; temporal and spatial coherence of partially coherent light.	CO2
III / 9 hrs	Electron–Field Interaction: Motion of a free electron in a plane electromagnetic wave; drift acceleration of electrons; elementary discussion of second harmonic generation during scattering of plane electromagnetic waves.	CO3
IV / 9 hrs	Nonlinear Polarization and Effects: Nonlinear polarization; classical model of an anharmonic oscillator; nonlinear susceptibilities and Miller’s rule; elementary discussion of self-focusing and self-steepening of light.	CO4
V / 9 hrs	Nonlinear Optical Phenomena: Simple explanation of the Kerr effect; elementary discussion of harmonic generation in dielectrics; concept and conditions for phase matching.	CO5

Suggested Readings

1. Boyd, R. W. (2008). *Nonlinear Optics* (3rd ed.). Academic Press.
2. Born, M., & Wolf, E. (1999). *Principles of Optics* (7th ed.). Cambridge University Press.
3. Shen, Y. R. (2003). *The Principles of Nonlinear Optics*. Wiley-Interscience.
4. Hecht, E. (2017). *Optics* (5th ed.). Pearson Education.
5. Ghatak, A., & Thyagarajan, K. (2010). *Optical Electronics*. Cambridge University Press.
6. Loudon, R. (2000). *The Quantum Theory of Light* (3rd ed.). Oxford University Press.

L T P Cr

3 1 0 4

Course Title: Quantum States of Radiation

Course Code: PHY658

Total Hours: 45

Course Objectives

- To establish a foundational understanding of coherent states of radiation, including their definition and properties, and to enable the representation of quantum states and operators using these states.
- To describe the density operator formalism for characterizing radiation fields and to explain the Sudarshan-Glauber P-representation for both coherent and chaotic light.
- To analyze the quantum description of polarization, including the use of Stokes parameters and the formulation of creation/annihilation operators for generally polarized modes.
- To interpret photon counting statistics and correlation experiments, such as the Hanbury Brown-Twiss experiment, and to explain the quantum phenomena of photon bunching and antibunching.
- To discuss non-classical properties of light using mathematical tools like Schwarz inequalities and to describe the fundamental characteristics and significance of squeezed states of radiation.

Course Outcomes

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

CO1. Explain the concept and properties of coherent states of radiation and represent quantum states and operators in terms of these states.

CO2. Describe the density operator formalism and the Sudarshan–Glauber representation for coherent and chaotic radiation fields.

CO3. Analyze polarization in quantum optics using Stokes parameters and operators for general polarization states.

CO4. Interpret photon counting statistics, including the Hanbury Brown–Twiss experiment, and explain bunching and antibunching phenomena in radiation fields.

CO5. Discuss the quantum nature of light using Schwarz inequalities and describe the characteristics of squeezed states of radiation.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1			1
CO2	3	3	2	3	3	3	1	2	3	1		1			1
CO3	3	3	1	3	3	3	1	2	3	1		1			1
CO4	3	3	1	3	3	3	1	2	3	1		1			1
CO5	3	3	1	3	3	3	1	2	3	1		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	Coherent States of Radiation: Definition and properties of coherent states; coherent state as a wave packet; expansion of quantum states and operators in terms of coherent states.	CO1
II / 9 hrs	Density Operator and Representations: Density operator of radiation; Sudarshan–Glauber P-representation; density operators of coherent and chaotic radiation; coherence and characteristic functions.	CO2
III / 9 hrs	Polarization in Quantum Optics: Quantum description of polarization; Stokes parameters; annihilation and creation operators for modes with general polarization; description of unpolarized light.	CO3
IV / 9 hrs	Photon Statistics and Correlation: Photoelectron counting distributions; Hanbury Brown and Twiss experiment; photon bunching and antibunching; illustration of antibunching using pure Fock states.	CO4
V / 9 hrs	Quantum Behaviour of Optical Fields: Schwarz inequalities; nonclassical light properties; elementary discussion of squeezed states of radiation and their physical significance.	CO5

Suggested Readings

1. Loudon, R. (2000). *The Quantum Theory of Light* (3rd ed.). Oxford University Press.
2. Walls, D. F., & Milburn, G. J. (2008). *Quantum Optics* (2nd ed.). Springer.
3. Scully, M. O., & Zubairy, M. S. (1997). *Quantum Optics*. Cambridge University Press.
4. Mandel, L., & Wolf, E. (1995). *Optical Coherence and Quantum Optics*. Cambridge University Press.
5. Gerry, C., & Knight, P. (2005). *Introductory Quantum Optics*. Cambridge University Press.

X-RAY AND ION BEAM

L T P Cr

3 1 0 4

Course Title: X-Ray Physics and Instrumentation

Course Code: PHY659

Total Hours: 45

Course Objectives

- To explain the production, properties, and spectra of X-rays, including their dispersion and refraction.
- To understand the theory of the photoelectric effect, secondary spectra, and screening effects in X-ray emission.
- To analyze the fine structure of absorption edges and the relative intensities of X-ray spectral lines.
- To describe the construction and working principles of various X-ray generators and detection systems.
- To apply X-ray spectroscopic techniques (XPS, AES, EXAFS, XANES) for material analysis.

Course Outcomes

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

CO1. Explain the production, properties, and spectra of X-rays, and describe their dispersion and refraction behavior.

CO2. Understand the theory and experimental aspects of the photoelectric effect, secondary spectra, and screening effects in X-ray emission.

CO3. Analyze the fine structure of absorption edges, absorption discontinuities, and relative intensities of X-ray spectral lines.

CO4. Describe the construction and working principles of various X-ray generators and detection systems.

CO5. Apply X-ray spectroscopic techniques such as XPS, AES, EXAFS, and XANES for structural and electronic analysis of materials.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	1	3	2	3	1	3	3	1		1			1
CO2	3	3	1	3	3	3	1	3	3	1		1			1
CO3	3	3	1	3	3	3	1	3	3	1		1			1
CO4	3	2	1	3	1	3	1	3	3	1		1			1
CO5	3	3	1	3	3	3	1	3	3	2		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	General X-Ray Physics: Energy spectrum of X-rays; continuous and characteristic spectra; Kramers' theory of X-ray production from thin and thick targets; dispersion theory and refraction of X-rays.	CO1
II / 9 hrs	Photoelectric Effect and Spectra: Theory and observation of the photoelectric effect; secondary spectra; screening doublets; X-ray energy level diagrams; forbidden lines and their significance.	CO2
III / 9 hrs	Absorption and Fine Structure: Relative intensities of X-ray lines; theory of fine structure of absorption edges; absorption discontinuity and its physical interpretation.	CO3
IV / 9 hrs	X-Ray Generation and Detection: Types of X-ray tubes—sealed source, rotating anode, and synchrotron; auxiliary equipment; detection of X-rays using photographic and electronic detectors.	CO4
V / 9 hrs	X-Ray Spectroscopic Techniques: One-crystal, bent-crystal, and double-crystal spectrometers; ruled gratings in X-ray spectroscopy; soft X-ray spectroscopy; valence band spectra; XPS (X-ray Photoelectron Spectroscopy), AES (Auger Electron Spectroscopy), EXAFS (Extended X-ray Absorption Fine Structure), and XANES (X-ray Absorption Near Edge Structure).	CO5

Suggested Readings

1. Jenkins, R., & Gould, R. W. (1981). *X-ray Spectrometry: Chemical Analysis*. Wiley.
2. Als-Nielsen, J., & McMorrow, D. (2011). *Elements of Modern X-ray Physics* (2nd ed.). Wiley.
3. Lipson, H., & Steeple, H. (1970). *Interpretation of X-ray Powder Diffraction Patterns*. Macmillan.
4. Cullity, B. D., & Stock, S. R. (2014). *Elements of X-Ray Diffraction* (3rd ed.). Pearson.
5. Klug, H. P., & Alexander, L. E. (1974). *X-ray Diffraction Procedures for Polycrystalline and Amorphous Materials*. Wiley.
6. Hummel, R. E. (2007). *Electronic Properties of Materials* (4th ed.). Springer.

L T P Cr

3 1 0 4

Course Title: Beam Physics and Instrumentation

Course Code: PHY660

Total Hours: 45

Course Objectives

- To explain the fundamental parameters that define charged particle beams, such as emittance and brightness, and to describe the interactions of particles with matter, including energy loss mechanisms and space charge effects.
- To describe the working principles, ion extraction methods, and applications of various beam sources, including positive/negative ion sources, ECR sources, and atomic/molecular beam sources.
- To understand the basic operating principles of different particle accelerators, the function of beam-manipulating elements, and key concepts in beam dynamics such as betatron motion, tune, and luminosity.
- To identify and evaluate the characteristics of various particle detection systems, including gas detectors, calorimeters, semiconductor detectors, and Cherenkov counters, based on their sensitivity, efficiency, and response.
- To understand modern data acquisition systems for beam control and to apply numerical and statistical methods, including error analysis and Monte Carlo techniques, for signal processing and measurement.

Course Outcomes

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

CO1. Explain the fundamental parameters of charged particle beams such as emittance, brightness, and space charge effects, and describe particle–matter interactions and energy loss

mechanisms.

CO2. Describe various beam source types, their working principles, and applications, including ion and molecular beam sources.

CO3. Understand the basic design and operation principles of particle accelerators and beam manipulation elements.

CO4. Identify different beam detection systems and evaluate their characteristics, including sensitivity, efficiency, and response.

CO5. Understand modern control and data acquisition systems used in beam instrumentation and apply numerical and statistical methods in signal analysis and measurement.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	2	3	1	3	3	1		1			1
CO2	3	2	1	3	1	3	1	3	3	1		1			1
CO3	3	3	1	3	2	3	1	3	3	2		1			1
CO4	3	2	1	3	1	3	1	3	3	1		1			1
CO5	3	3	3	3	1	3	1	3	3	2		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours Contents	Mapping with Course Outcome
I / 9 hrs General Concepts: Emittance and brightness; effects of space charge in charged particle sources; interaction of particles with matter—cross-section, survival probability, mean free path, and energy loss of heavy particles.	CO1
II / 9 hrs Beam Sources: Overview of beam sources and their applications; ion extraction and focusing geometries; positive and negative ion sources; radio-frequency and ECR (Electron Cyclotron Resonance) sources; atomic and molecular beam sources.	CO2
III / 9 hrs Accelerator and Beam Dynamics: Overview of accelerator types; beam-manipulating elements; beam acceptance; betatron motion; lattice functions; tune and phase stability; luminosity and beam cooling; representative examples of accelerators.	CO3

Units/Hours Contents		Mapping with Course Course Outcome
IV / 9 hrs	Detection and Control Systems: Transition radiation; detector characteristics—sensitivity, response, efficiency, dead time; gas detectors; calorimeters; semiconductor detectors; Cherenkov counters; scintillation chambers.	CO4
V / 9 hrs	Data Acquisition and Signal Processing: Interface buses for control instrumentation (e.g., CAMAC); current trends in data acquisition; interpolation; error propagation; Gaussian quadrature; Monte Carlo method; signal-to-noise ratio; pulse shaping, amplification, and timing measurements.	CO5

Suggested Readings

1. Wiedemann, H. (2015). *Particle Accelerator Physics* (4th ed.). Springer.
2. Humphries, S. (2017). *Charged Particle Beams*. Dover Publications.
3. Livingston, M. S., & Blewett, J. P. (1962). *Particle Accelerators*. McGraw-Hill.
4. Knoll, G. F. (2010). *Radiation Detection and Measurement* (4th ed.). Wiley.
5. Leo, W. R. (1994). *Techniques for Nuclear and Particle Physics Experiments*. Springer.
6. Reiser, M. (2008). *Theory and Design of Charged Particle Beams* (2nd ed.). Wiley-VCH.

NUCLEAR AND PARTICLE PHYSICS

L T P Cr

3 1 0 4

Course Title: Advanced Nuclear and Particle Physics – I

Course Code: PHY661

Total Hours: 45

Course Objectives

- To apply angular momentum algebra and rotational invariance principles to nuclear systems.
- To utilize spherical tensor formalism and the Wigner-Eckart theorem for calculating matrix elements in nuclear physics.
- To explain and apply the nuclear shell model, mean field models, and configuration mixing techniques.
- To perform energy level calculations for nuclear spectra using advanced shell model approaches.

- To analyze collective nuclear models, vibrational and rotational modes, and phenomena at high spin.

Course Outcomes

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

CO1. Apply angular momentum algebra and rotational invariance principles to nuclear systems.

CO2. Utilize spherical tensor formalism and the Wigner–Eckart theorem for matrix element calculations in nuclear models.

CO3. Explain and apply the nuclear shell model, mean field models, and configuration mixing techniques for describing nuclear structure.

CO4. Perform energy level calculations and interpret nuclear spectra using advanced shell model approaches including Monte Carlo methods.

CO5. Analyze collective nuclear models, vibrational and rotational modes, and understand phenomena like back bending, high-spin states, and deformed nuclear shapes.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	2	3	1	3	3	1		1			1
CO2	3	2	1	3	1	3	1	3	3	1		1			1
CO3	3	3	1	3	2	3	1	3	3	2		1			1
CO4	3	2	1	3	1	3	1	3	3	1		1			1
CO5	3	3	3	3	1	3	1	3	3	2		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Course Outcome
I / 9 hrs	Review of Theoretical Techniques I: Rotational invariance in three dimensions; eigenvalues and eigenfunctions of angular momentum operators; addition of angular momenta; Clebsch–Gordan coefficients and their applications in nuclear states.	CO1
II / 9 hrs	Review of Theoretical Techniques II: Spherical tensors; Wigner–Eckart theorem and applications; occupation number	CO2

Units/Hours	Contents	Mapping with Course Outcome
	representation; calculation of matrix elements for one- and two-body symmetric operators.	
III / 9 hrs	Nuclear Shell Model: Common potential $V(r)$ in spherical shell model; wave functions and quantum numbers; two-particle systems outside a COsed core; residual and effective interactions; configuration mixing; transformation to center-of-mass and relative coordinates; Moshinsky brackets; mean-field models—Hartree–Fock, Hartree–Fock–Bogoliubov, and pairing plus quadrupole interactions.	CO3
IV / 9 hrs	Energy Level Calculations: Spectra of COsed-shell nuclei; one-particle–one-hole (1p–1h) excitations; configurations with three or more particles outside a COsed core; coefficients of fractional parentage; Shell Model Monte Carlo methods and numerical approaches to spectra.	CO4
V / 9 hrs	Collective Models: Nuclear vibrations and isoscalar vibrations; sum rule in vibrational models; giant resonances; Bohr–Mottelson collective model; back bending, high-spin states, superdeformed and hyperdeformed shapes; Nilsson model for nonspherical nuclei; coupling of single-particle and collective motions in the unified model.	CO5

Suggested Readings

1. Bohr, A., & Mottelson, B. R. (1998). *Nuclear Structure* (Vols. I & II). World Scientific.
2. Heyde, K. L. G. (1994). *The Nuclear Shell Model*. Springer.
3. Preston, M. A., & Bhaduri, R. K. (1993). *Structure of the Nucleus*. Addison-Wesley.
4. Wong, S. S. M. (2004). *Introductory Nuclear Physics* (2nd ed.). Wiley-VCH.
5. Talmi, I. (1993). *Simple Models of Complex Nuclei: The Shell Model and Interacting Boson Model*. Harwood Academic Press.
6. Ring, P., & Schuck, P. (2004). *The Nuclear Many-Body Problem*. Springer.

L T P Cr

3 1 0 4

Course Title: Advanced Nuclear and Particle Physics – II

Course Code: PHY662

Total Hours: 45

Course Objectives

- To explain the profound connection between symmetries and conservation laws in particle physics using Noether's theorem and to analyze the implications of discrete symmetries (P, C, T) and the CPT theorem.
- To describe the SU(2) and SU(3) symmetry groups and apply them within the quark model for the systematic classification of hadrons into meson and baryon multiplets.
- To understand the principles of quantizing free fields, including the canonical and covariant quantization of scalar, electromagnetic, and Dirac fields, and their physical interpretation.
- To apply the core techniques of quantum field theory—including interaction Hamiltonians, Wick's theorem, and Feynman diagrams with propagators—to analyze elementary scattering processes like Compton scattering.
- To analyze the fundamental components of particle physics experiments, including accelerator types (fixed-target and colliding beams) and detection methods, and to understand their role in major discoveries such as the J/ψ particle.

Course Outcomes

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

CO1. Explain the role of symmetries and conservation laws in particle physics using Noether's theorem and discrete symmetries (P, C, T, and CPT).

CO2. Describe SU(2) and SU(3) symmetry groups and their application to the classification of hadrons in the quark model.

CO3. Understand field quantization concepts for scalar, electromagnetic, and Dirac fields and their physical implications.

CO4. Apply quantum field theory techniques including interaction Hamiltonians, Feynman diagrams, and propagators to scattering processes.

CO5. Analyze experimental setups and discoveries in particle physics, including accelerators, detection methods, and major findings such as the discovery of J/ψ .

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1			1
CO2	3	3	2	3	3	3	1	2	3	1		1			1
CO3	3	3	2	3	3	3	1	2	3	1		1			1
CO4	3	3	2	3	3	3	1	2	3	1		1			1
CO5	3	2	2	3	2	3	1	3	3	2	1	1	2		1

- 1 = High Mapping
2 = Moderate Mapping
3 = Strong Mapping

Course Content

Units/Hours	Contents	Mapping with Course Outcome
I / 9 hrs	Symmetries and Conservation Laws: Symmetries and their connection to conservation laws; Noether's theorem; discrete symmetries—parity (P), charge conjugation (C), and time reversal (T); CPT theorem; G-parity; SU(2) isospin symmetry and applications.	CO1
II / 9 hrs	SU(3) and the Quark Model: SU(3) symmetry and quark model; classification of mesons and baryons; hadron multiplets; meson and baryon spectra and the eightfold way.	CO2
III / 9 hrs	Quantization of Fields: Elementary particles as fields; quantization of free fields; scalar and electromagnetic field quantization—canonical and covariant approaches.	CO3
IV / 9 hrs	Dirac Fields: Dirac equation and its physical interpretation; helicity and chirality; quantization of Dirac fields and applications to fermionic systems.	CO3
V / 9 hrs	Quantum Field Interactions and Experiments: Interaction Hamiltonian in normal form; chronological products and Wick's theorem; S-matrix formulation; Feynman diagrams and propagators; Feynman rules and Compton scattering; basics of particle accelerators, fixed target and colliding beam experiments, particle detection methods, and the discovery of J/ ψ .	CO4, CO5

Suggested Readings

1. Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd ed.). Wiley-VCH.
2. Halzen, F., & Martin, A. D. (1984). *Quarks and Leptons: An Introductory Course in Modern Particle Physics*. Wiley.
3. Bjorken, J. D., & Drell, S. D. (1964). *Relativistic Quantum Mechanics*. McGraw-Hill.
4. Peskin, M. E., & Schroeder, D. V. (1995). *An Introduction to Quantum Field Theory*. Addison-Wesley.
5. Perkins, D. H. (2000). *Introduction to High Energy Physics* (4th ed.). Cambridge University Press.
6. Mandl, F., & Shaw, G. (2010). *Quantum Field Theory* (2nd ed.). Wiley.

SEMESTER – IV

Paper – I: EXPERIMENTAL TECHNIQUES & CONTROL SYSTEMS

Course Code: PHY603

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To develop a foundational understanding of data interpretation, including the concepts of precision and accuracy, and to apply statistical methods for error analysis, propagation, and curve fitting to experimental data.
- To understand the working principles and practical applications of key optoelectronic devices (e.g., solar cells, photodetectors) and transducers (e.g., for temperature, pressure, vacuum).
- To acquire knowledge of fundamental measurement and control systems, including signal conditioning, and to master the characteristics and applications of ideal operational amplifiers in various circuit configurations.
- To differentiate between analog and digital data systems, understand the sampling theorem, and analyze the operation of various Analog-to-Digital (A/D) and Digital-to-Analog (D/A) converters.
- To apply Fourier transform techniques for signal analysis, understand the working principle of lock-in detectors for signal recovery, and grasp the basics of microprocessor and microcontroller systems for instrument control.

Course Outcomes (COs):

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

CO1: Develop understanding of data interpretation, precision, accuracy, and statistical error analysis.

CO2: Understand working principles and applications of optoelectronic devices and transducers.

CO3: Acquire knowledge of measurement and control systems and operational amplifiers.

CO4: Differentiate between analog and digital data systems, and understand A/D and D/A converters.

CO5: Apply Fourier transform techniques and understand the working of lock-in detectors and microprocessor-based systems.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	2	3	3	3	1	3	1	3	3	2	1	2			1
CO2	3	2	1	3	1	3	1	3	3	2	1	1			1
CO3	3	2	1	3	1	3	1	3	3	2	2	1			1
CO4	2	3	2	3	1	3	1	3	3	2	1	1			1

CO5	2	3	2	3	1	3	1	3	3	2	1	1			1
-----	---	---	---	---	---	---	---	---	---	---	---	---	--	--	---

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Course Outcome
Unit I / 9	Data Interpretation and Analysis: Precision and accuracy, error analysis, propagation of errors, least squares fitting, linear and nonlinear curve fitting, chi-square test.	CO1
Unit II / 9	Optoelectronic Devices and Detectors: Solar cells, photodetectors, transducers (temperature, pressure), vacuum pumps and gauges.	CO2
Unit III / 9	Measurement and Control Systems: Signal conditioning and recovery, impedance matching. Ideal operational amplifier – characteristics and applications: inverting and non-inverting amplifier, integrator, differentiator, adder and comparator circuits.	CO3
Unit IV / 9	Analogue versus Digital Data: Statement of sampling theorem. A/D Converters: Flash, single slope, double slope, and successive approximation converters. D/A Converters: R–2R ladder type and weighted resistor type. Digital Filters: Tapped delay line filter.	CO4
Unit V / 9	Fourier Transforms and Lock-in Detector: Box-car averaging, signal enhancement techniques. Microprocessor and Microcontroller Basics: Instruction set related to MOV, MVI, and I/O commands. Addressing I/O devices (Memory-mapped and I/O-mapped I/O).	CO5

Suggested Readings:

1. Horowitz P. and Hill W. (2015). *The Art of Electronics*. Cambridge University Press.
2. Malvino A. P. and Bates D. (2017). *Electronic Principles*. McGraw-Hill Education.
3. Helfrick A. D. and Cooper W. D. (1990). *Modern Electronic Instrumentation and Measurement Techniques*. Prentice Hall.
4. Kalsi H. S. (2012). *Electronic Instrumentation*. McGraw-Hill Education, India.
5. Bolton W. (2009). *Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering*. Pearson Education.

ELECTIVE PAPER

Paper – II (Elective – I): PROGRAMMING FOR NUMERICAL METHODS

Course Code: PHY663

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To introduce the fundamental syntax of C++ programming, including data types, keywords, and control structures, for building a solid foundation in procedural programming.
- To enable students to demonstrate proficiency in using core C++ programming elements such as operators, arrays, structures, and pointers for effective data handling and manipulation.
- To establish an understanding of Object-Oriented Programming (OOP) paradigms and to apply the concepts of classes and objects for solving basic computational problems.
- To develop and implement C++ programs that solve standard numerical problems, including finding roots of equations, performing numerical integration and interpolation, and executing matrix operations.
- To implement C++ programs for solving ordinary differential equations using numerical methods (Euler, Runge-Kutta) and to analyze the resulting dynamics, including phase space trajectories and system stability.

Course Outcomes (COs):

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

CO1: Understand the fundamentals of C++ programming, including syntax, data types, and control structures.

CO2: Demonstrate the use of operators, arrays, structures, and pointers in C++ programming.

CO3: Understand the concept of Object-Oriented Programming (OOP) and apply classes and objects for problem-solving.

CO4: Develop and implement C++ programs for solving numerical problems such as roots of equations, integration, interpolation, and matrix operations.

CO5: Implement C++ programs for solving differential equations using Euler and Runge-Kutta methods and analyze physical systems for stability and equilibrium.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	1	2	1	2	1	2	1	3	2	1	1	1			3
CO2	1	2	1	2	1	2	1	3	2	1	1	1			3
CO3	1	2	1	2	1	2	1	3	2	1	2	1			3
CO4	2	3	2	3	2	3	1	3	3	2	1	1			3
CO5	3	3	2	3	2	3	1	3	3	2	1	1			3

- 1 = High Mapping
 2 = Moderate Mapping
 3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Outcome
Unit I / 9	C++ Basics: Keywords, various data types, implicit conversions. Control structures: <i>for</i> , <i>while</i> , and <i>do-while</i> loops, <i>break</i> and <i>continue</i> statements, <i>switch</i> statement, <i>if-else</i> , and conditional operator. Functions with default arguments, function overloading.	CO1
Unit II / 9	Operators and Data Handling: Increment (++) and decrement (–) operators, arrays, structures, pointers, compound assignment operators.	CO2
Unit III / 9	Object-Oriented Programming Concepts: Definition of class and object, declaration of classes and objects, simple applications of OOP for numerical problem-solving.	CO3
Unit IV / 9	Programming for Numerical Methods (Part I): C++ programs for Newton-Raphson method, iterative method, numerical integration using Trapezoidal and Simpson's 1/3 rule, interpolation, and matrix manipulations.	CO4
Unit V / 9	Programming for Numerical Methods (Part II): C++ programs for Euler's method and Runge-Kutta (second order and fourth order) method. Phase space trajectory, equilibrium points, and stability analysis.	CO5

Suggested Readings:

1. Balagurusamy E. (2017). *Object-Oriented Programming with C++*. McGraw-Hill Education, India.
2. Venugopal K. R., Rajkumar and Ravishankar T. (2006). *Mastering C++*. Tata McGraw-Hill Education.
3. Yadav J. S. (2015). *Numerical Methods in C and C++*. University Science Press, India.
4. Press W. H. et al. (2007). *Numerical Recipes in C++: The Art of Scientific Computing*. Cambridge University Press.
5. Chapra S. C. and Canale R. P. (2015). *Numerical Methods for Engineers*. McGraw-Hill Education.

ELECTIVE PAPER

Paper – II (Elective – II): ELECTRODYNAMICS AND SECOND QUANTIZATION**Course Code:** PHY664**L–T–P–Cr:** 3–1–0–4**Total Hours:** 45**Course Objectives**

- To establish a foundational understanding of electromagnetic radiation from moving charges, including the use of Green's function techniques to solve the inhomogeneous wave equation and derive the Liénard-Wiechert potentials.
- To analyze the angular distribution of radiated power and understand the characteristics of electromagnetic fields produced by accelerated charges and oscillating localized sources.
- To understand the concept of radiation reaction and self-force, its derivation from energy conservation principles, and its implications for phenomena such as the natural line width of spectral lines.
- To apply the covariant Lagrangian formulation for fields and Noether's theorem to systematically derive conserved quantities, including the energy-momentum tensor and angular momentum tensor.
- To comprehend the fundamental process of second quantization for scalar, electromagnetic, and Dirac fields, and to perform basic algebraic operations with creation and annihilation operators.

Course Outcomes (COs):

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

CO1: Understand the fundamentals of radiation from moving charges and apply Green's function techniques to solve electromagnetic problems.

CO2: Analyze angular distribution and electromagnetic radiation from oscillating localized sources.

CO3: Understand the concept of radiation reaction, self-force, and their relation to energy conservation and spectral line width.

CO4: Apply covariant Lagrangian formalism and Noether's theorem to derive conserved quantities such as energy-momentum and angular momentum tensors.

CO5: Comprehend the process of second quantization for scalar, electromagnetic, and Dirac fields and perform basic operator algebra related to field quantization.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	1	3	3	3	1	3	3	1	2	1			1
CO2	3	3	1	3	3	3	1	3	3	1	2	1			1
CO3	3	3	2	3	3	3	1	3	3	1	1	1			1

CO4	3	3	1	3	3	3	1	3	3	1	2	1			1
CO5	3	3	1	3	3	3	1	3	3	1	1	1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Outcome
Unit I / 9	Radiation from a Moving Charge: Solution of inhomogeneous wave equation, Green's functions, Liénard–Wiechert potentials, and field from a moving charge. Larmor's formula and its relativistic generalization.	CO1
Unit II / 9	Angular Distribution of Radiation: Radiation from an accelerated charge, electromagnetic field, and radiation from an oscillating localized source.	CO2
Unit III / 9	Radiation Reaction and Self-Force: Derivation of radiation reaction force using energy conservation principles. Line width and level shift of an oscillator.	CO3
Unit IV / 9	Covariant Lagrangian Formalism: Lagrangian formulation for fields, Noether's theorem, conserved quantities – energy-momentum tensor, angular momentum and spin tensors, current density four-vector.	CO4
Unit V / 9	Second Quantization: Quantization of scalar field, electromagnetic field in radiation gauge, and Dirac field. Spin of photons. Simple problems on the algebra of annihilation and creation operators.	CO5

Suggested Readings:

1. Jackson J. D. (1999). *Classical Electrodynamics*. Wiley, New York.
2. Landau L. D. and Lifshitz E. M. (1982). *The Classical Theory of Fields*. Pergamon Press, Oxford.
3. Greiner W. (1998). *Field Quantization*. Springer-Verlag, Berlin.
4. Mandl F. and Shaw G. (2010). *Quantum Field Theory*. John Wiley & Sons, UK.
5. Sakurai J. J. (2017). *Advanced Quantum Mechanics*. Pearson Education, India.

ELECTIVE PAPER

Paper – II (Elective – III): GROUP THEORY

Course Code: PHY665

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To introduce the fundamental abstract concepts of group theory, including the definitions of groups, subgroups, cosets, and classes, and to explore operations such as direct products.
- To develop a rigorous understanding of the theory of group representations, including matrix representations of operators, character theory, and the classification into reducible and irreducible representations using Schur's lemmas.
- To enable students to apply the powerful orthogonality theorems for irreducible representations and characters, and to understand the concept and significance of the regular representation.
- To establish the connection between group theory and quantum mechanics by exploring how symmetry transformations, degeneracy, and invariant subspaces are formally described using representation theory.
- To apply group theoretical methods to the analysis of molecular and crystal symmetry by constructing the 32 crystallographic point groups and their corresponding character tables.

Course Outcomes (COs):

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

CO1: Understand the fundamental concepts of group theory including groups, subgroups, cosets, and group operations.

CO2: Develop understanding of matrix representations of operators and the theory of representations of groups.

CO3: Apply orthogonality theorems for irreducible representations and understand reducible versus irreducible representations.

CO4: Relate group theory to quantum mechanics through symmetry transformations, degeneracy, and invariant subspaces.

CO5: Apply group theory concepts to molecular and crystal symmetries, including construction of point groups and character tables.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	1	3	2	3	1	2	3	1	2	1			1
CO2	3	3	1	3	3	3	1	2	3	1	2	1			1
CO3	3	3	1	3	3	3	1	2	3	1	1	1			1
CO4	3	3	1	3	3	3	1	2	3	1	1	1			1
CO5	3	3	1	3	2	3	1	2	3	1	2	1			1

- 1 = High Mapping
2 = Moderate Mapping
3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Outcome
Unit I / 9	Introduction to Group Theory and Applications: Abstract definitions, group and multiplication table, subgroups, isomorphism and homomorphism, complexes, cosets and classes, indirect groups, and direct product of groups.	CO1
Unit II / 9	Theory of Representation: Linear vector space, basis, matrix representation of operators, unitary space, and unitary matrices. Representation of groups, characters, reducible and irreducible representations, invariant subspaces, Schur's lemmas.	CO2
Unit III / 9	Orthogonality Theorem and Regular Representation: Orthogonality theorem for irreducible representations and characters, regular representation, occurrence of an irreducible representation in a reducible representation.	CO3
Unit IV / 9	Number of Irreducible Representations and Quantum Mechanics Connection: Theorem for possible number of irreducible representations of a group, direct product of representations. Relationship to quantum mechanics – symmetry transformations, degeneracy, invariant subspaces, projection operators, and transformation of functions.	CO4
Unit V / 9	Applications to Molecular and Crystal Symmetry: Fundamental point group operations and nomenclature. Construction of thirty-two point groups and character tables for their irreducible representations.	CO5

Suggested Readings:

1. Tinkham M. (2003). *Group Theory and Quantum Mechanics*. Dover Publications, USA.
2. Cotton F. A. (2008). *Chemical Applications of Group Theory*. Wiley India Pvt. Ltd., New Delhi.
3. Hamermesh M. (1989). *Group Theory and Its Application to Physical Problems*. Dover Publications, USA.
4. Joshi A. W. (1997). *Elements of Group Theory for Physicists*. New Age International Publishers, India.
5. Tung W. K. (1985). *Group Theory in Physics*. World Scientific Publishing, Singapore.

SPECIAL PAPER

Paper – III: CONDENSED MATTER PHYSICS – I

Course Code: PHY666

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To establish the principles of transport theory by introducing phenomenological coefficients and to enable students to apply the Boltzmann transport equation for analyzing electrical and thermal transport phenomena.
- To analyze the distinct contributions of electrons and the lattice to electrical conductivity, thermal conductivity, and thermoelectric effects (Peltier, Seebeck) in both metals and semiconductors.
- To develop an understanding of the origins of magnetism, from the limitations of classical theories to semi-classical models involving exchange interaction, the Ising model, and various types of magnetic ordering (ferro-, antiferro-, ferrimagnetism).
- To apply the formalism of second quantization, specifically using Holstein-Primakoff transformations, to derive and analyze the properties of magnons in both ferromagnetic and antiferromagnetic systems.
- To understand the theory of continuous phase transitions in magnetic systems, including the concepts of an order parameter, Landau's phenomenological theory, and the elementary ideas of critical exponents and scaling.

Course Outcomes (COs):

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

CO1: Understand the principles of transport theory and apply the Boltzmann equation to study electrical and thermal transport.

CO2: Analyze electronic and lattice contributions to electrical, thermal, and thermoelectric effects in metals and semiconductors.

CO3: Develop understanding of classical and semi-classical theories of magnetism including exchange interaction, Ising model, and magnetic ordering.

CO4: Apply the second quantization approach to study ferromagnetic and antiferromagnetic systems using magnons.

CO5: Understand the theory of magnetic phase transitions, Landau's theory, and concepts of critical exponents and scaling.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	3	3	3	3	1	2	3	1		1			1
CO2	3	3	2	3	3	3	1	2	3	1		1			1
CO3	3	3	3	3	3	3	1	2	3	1		1			1

CO4	3	3	2	3	3	3	1	2	3	1		1			1
CO5	3	3	3	3	3	3	1	2	3	1		1			1

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Outcome
Unit I / 9	Transport Theory: Phenomenological coefficients L_{ij} and their physical interpretation. General Boltzmann equation and its linearization. Entropy production and relaxation time solution of the Boltzmann equation.	CO1
Unit II / 9	Electronic and Lattice Contributions: Electronic contributions to thermal and electrical conductivities and to Peltier and Seebeck coefficients for metals and semiconductors. Relationship between electrical and thermal conductivities; lattice contribution to thermal conductivity.	CO2
Unit III / 9	Magnetism – Classical and Semi-Classical Theories: Limitations of classical theory in explaining large internal fields. Exchange interaction, Ising model, Bragg–Williams approximation, non-existence of ferromagnetism in two-dimensional Ising model. Two-sublattice model, classical theories of antiferromagnetism and ferrimagnetism. Overview of ferrites and garnets.	CO3
Unit IV / 9	Second Quantized Theory of Magnetism: Ferromagnetic Heisenberg Hamiltonian, Holstein–Primakoff transformations and their application to Heisenberg Hamiltonian for small spin reversal fractions. Ferromagnetic magnons, magnon heat capacity, and saturation magnetization at low temperatures. Antiferromagnetic Hamiltonian and its reduction using Holstein–Primakoff transformation, antiferromagnetic magnons, zero-point sublattice magnetization.	CO4
Unit V / 9	Magnetic Phase Transition: Order parameter, Landau’s theory of second-order phase transitions, fluctuations of the order parameter. Elementary qualitative ideas about critical exponents and scaling. <i>Course Activities:</i> Analytical exercises and discussion on Landau theory and scaling behavior.	CO5

Suggested Readings:

1. Kittel C. (2005). *Introduction to Solid State Physics*. Wiley, New York.
2. Ashcroft N. W. and Mermin N. D. (2011). *Solid State Physics*. Cengage Course, USA.

3. Blundell S. (2001). *Magnetism in Condensed Matter*. Oxford University Press, UK.
4. Marder M. P. (2010). *Condensed Matter Physics*. Wiley-VCH, Germany.
5. Mattis D. C. (1988). *The Theory of Magnetism*. Springer-Verlag, Berlin.

SPECIAL PAPER

Paper – IV: CONDENSED MATTER PHYSICS – II

Course Code: PHY667

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To introduce the formalism of second quantization for fermionic systems, enabling students to define field operators and construct Hamiltonians for many-electron systems with Coulomb and screened interactions.
- To teach the application of linear response theory for calculating the dielectric properties of an electron gas, leading to the derivation of the Lindhard formula and an understanding of electrostatic screening.
- To establish a fundamental understanding of electron-phonon interactions, including the deformation potential model, and to explore their consequences, such as the formation of polarons.
- To enable students to analyze how electron-electron interactions and dielectric screening manifest in and influence macroscopic transport and optical properties of solids.
- To develop strong problem-solving skills by applying the techniques of second quantization and perturbation theory to solve advanced problems in condensed matter physics.

Course Outcomes (COs):

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

CO1: Understand the concept of second quantization for many-electron systems and formulate Hamiltonians for interacting electrons.

CO2: Apply linear response theory to analyze dielectric properties and screening in electron gases.

CO3: Understand the fundamentals of electron–phonon interactions and their role in lattice dynamics and polaron formation.

CO4: Analyze the impact of electron interactions and screening on transport and optical properties of solids.

CO5: Develop problem-solving skills for applying second quantized formalism and perturbation techniques in condensed matter systems.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
----------------------------	----------	----------	----------	----------	----------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	----------

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

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with Course Course Outcome
Unit I / 15	Many-Electron Systems: Second quantization for fermions, field operators, and electron density operator. Hamiltonian for two-particle interactions in second quantized form: Coulomb and screened Coulomb interactions.	CO1, CO5
Unit II / 15	Linear Response Theory: Dielectric response analysis, dielectric constant for electron gas in self-consistent approximation, Lindhard formula, dielectric constant and screening. Dielectric screening of a point charge impurity.	CO2, CO4
Unit III / 15	Electron-Phonon Interaction: Long-wavelength limit and deformation potential interaction. Born approximation, deformation potential perturbation Hamiltonian, normal processes, and concept of polaron. Number of phonons accompanying an electron.	CO3, CO4, CO5

Suggested Readings:

1. Mahan G. D. (2000). *Many-Particle Physics*. Springer Science & Business Media, New York.
2. Ashcroft N. W. and Mermin N. D. (2011). *Solid State Physics*. Cengage Course, USA.
3. Kittel C. (2005). *Introduction to Solid State Physics*. Wiley, New York.
4. Ziman J. M. (1972). *Principles of the Theory of Solids*. Cambridge University Press, UK.
5. Fetter A. L. and Walecka J. D. (2003). *Quantum Theory of Many-Particle Systems*. Dover Publications, USA.

SPECIAL PAPER

Paper – IV: CONDENSED MATTER PHYSICS – II

Course Code: PHY667

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To introduce the formalism of second quantization for fermionic systems, enabling students to define field operators and construct Hamiltonians for many-electron systems with Coulomb and screened interactions.
- To teach the application of linear response theory for calculating the dielectric properties of an electron gas, leading to the derivation of the Lindhard formula and an understanding of electrostatic screening.
- To establish a fundamental understanding of electron-phonon interactions, including the deformation potential model, and to explore their consequences, such as the formation of polarons.
- To explain the microscopic mechanism of superconductivity, focusing on the phonon-mediated attractive electron-electron interaction, the formation of Cooper pairs, and the resulting reduced Hamiltonian.
- To enable students to analyze the key properties of superconductors, including the energy gap, transition temperature, Meissner effect, and flux quantization, through the framework of the BCS theory.

Course Outcomes (COs)

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

CO1: Explain the concept of second quantization for fermionic systems and formulate many-body Hamiltonians.

CO2: Apply linear response theory to derive dielectric properties and screening in electron gases.

CO3: Describe the fundamentals of electron–phonon interactions and polaron formation.

CO4: Understand the mechanism of superconductivity through electron–phonon-mediated interactions and Cooper pairing.

CO5: Analyze superconducting ground and excited states, energy gaps, transition temperature, and Meissner effect.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	3	3	3	3	1	2	3	1		1		1	
CO2	3	3	2	3	3	3	1	2	3	1		1		1	
CO3	3	3	3	3	3	3	1	2	3	1		1		1	
CO4	3	3	2	3	3	3	1	2	3	1		1		1	
CO5	3	3	3	3	3	3	1	2	3	1		1		1	

- 1 = High Mapping
2 = Moderate Mapping
3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with COs
Unit I / 9 hrs	Many-Electron Systems: Second quantization for fermions, field operators, electron density operator, Hamiltonian for two-particle interactions in second quantized form. Coulomb and screened Coulomb interactions.	CO1
Unit II / 9 hrs	Linear Response Theory: Dielectric response analysis, dielectric constant for electron gas in self-consistent approximation, Lindhard formula, dielectric constant and dielectric screening of a point charge impurity.	CO2
Unit III / 9 hrs	Electron-Phonon Interaction: Long wavelength limit, deformation potential interaction, Born approximation, deformation potential perturbation Hamiltonian, normal processes, polaron, number of phonons accompanying an electron.	CO3
Unit IV / 9 hrs	Electron-Electron Interaction via Phonons: Attractive interaction, Cooper pairs, reduced Hamiltonian for superconducting state, Bogoliubov-Valatin transformation, diagonal and non-diagonal terms.	CO4
Unit V / 9 hrs	Superconductivity: Ground state energy, nature of ground and excited states, temperature dependence of energy gap, transition temperature, Meissner effect, and flux quantization.	CO5

Suggested Readings:

1. **Mahan, G. D.** (2000). *Many-Particle Physics*. Springer Science & Business Media, New York.
2. **Fetter, A. L. & Walecka, J. D.** (2003). *Quantum Theory of Many-Particle Systems*. Dover Publications, USA.
3. **Ashcroft, N. W. & Mermin, N. D.** (2011). *Solid State Physics*. Cengage Course, USA.
4. **Kittel, C.** (2005). *Introduction to Solid State Physics*. Wiley, New York.
5. **Schrieffer, J. R.** (1964). *Theory of Superconductivity*. Addison-Wesley, USA.
6. **Ziman, J. M.** (1972). *Principles of the Theory of Solids*. Cambridge University Press, UK.

SPECIAL PAPER – ELECTRONICS

Paper – III: MICROPROCESSOR

Course Code: PHY668

L-T-P-Cr: 3-1-0-4

Total Hours: 45

Course Objectives

- To describe the fundamental architecture of the Intel 8085 microprocessor, including its instruction set and programming model, for the development of simple assembly language programs.
- To explain the principles of memory organization and address decoding, and to analyze interfacing techniques for both memory-mapped and I/O-mapped schemes in microprocessor systems.
- To illustrate the detailed hardware configuration of the 8085 microprocessor, including the function of its control unit, ALU, registers, and the significance of its timing diagrams.
- To demonstrate the interfacing of key peripheral devices, such as the Programmable Interface Adapter (PIA 8255), RAM, and ROM, with the 8085 microprocessor, incorporating handshaking techniques.
- To design and implement interface circuits for analog-to-digital (A/D) and digital-to-analog (D/A) converters, and to analyze their operation and integration with a microprocessor system.

Course Outcomes (COs)

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

CO1: Describe the architecture, instruction set, and programming aspects of the Intel 8085 microprocessor.

CO2: Explain memory organization, mapping, and interfacing techniques in microprocessor systems.

CO3: Illustrate the hardware configuration and operational characteristics of 8085 microprocessor.

CO4: Demonstrate the interfacing of peripheral devices such as PIA 8255, RAM, and ROM with 8085.

CO5: Design and implement A/D and D/A converter interfacing circuits and analyze their functioning.

Mapping of Course outcomes:

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	2	2	3	1	3	2	3	2	1	1	2	1	1	2
CO2	3	3	2	3	1	3	2	3	3	2	1	2	1	1	2
CO3	3	2	2	3	1	3	2	3	2	1	1	2	1	1	2
CO4	3	3	2	3	1	3	2	3	3	2	1	2	1	1	2
CO5	3	3	2	3	1	3	2	3	3	2	1	2	1	1	2

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with COs
Unit I / 9 hrs	Microprocessor Fundamentals: Overview of microprocessor systems, architecture of Intel 8085, instruction set, addressing modes, and execution of simple assembly language programs.	CO1
Unit II / 9 hrs	Memory Organization and Interfacing: Memory mapping and organization, address decoding, I/O devices, chip select logic, interfacing in I/O-mapped and memory-mapped I/O schemes.	CO2
Unit III / 9 hrs	Hardware Description of 8085: Functional block diagram, control unit, ALU, registers, and timing diagrams.	CO3
Unit IV / 9 hrs	Peripheral Interfacing and Memory Devices: Programmable Interface Adapter (PIA 8255), handshaking via interrupt and polling, CMOS devices as RAM and ROM, and memory refresh mechanisms.	CO4
Unit V / 9 hrs	Data Conversion and Interfacing: A/D and D/A conversion principles, IC ADC0809 and DAC08 – pin configuration, operation, and interfacing with 8085 microprocessor.	CO5

Suggested Readings:

1. **Gaonkar, R. S.** (2013). *Microprocessor Architecture, Programming and Applications with 8085*. Penram International Publishing, India.
2. **Mathur, A. P.** (2008). *Introduction to Microprocessors*. Tata McGraw Hill, New Delhi.
3. **Brey, B. B.** (2009). *Intel Microprocessors: Architecture, Programming, and Interfacing*. Pearson Education, USA.
4. **Malvino, A. P., & Leach, D. P.** (1996). *Digital Principles and Applications*. Tata McGraw Hill, New Delhi.
5. **Hall, D. V.** (1986). *Microprocessors and Interfacing: Programming and Hardware*. Tata McGraw Hill, New Delhi.
6. **Kalsi, H. S.** (2007). *Electronic Instrumentation*. Tata McGraw Hill, New Delhi.

SPECIAL PAPER – ELECTRONICS

Paper – IV: SEMICONDUCTOR DEVICES

Course Code: PHY669

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To explain the fundamental physics of semiconductors, including the mechanisms governing carrier concentration, recombination, and carrier transport via drift and diffusion.
- To analyze the operational principles, current-voltage characteristics, capacitive behavior, and breakdown mechanisms of a p-n junction diode.
- To describe the quantum mechanical tunneling phenomenon and its application in devices like the tunnel diode, enabling operation as a high-frequency amplifier or oscillator.
- To evaluate the operating principles, performance characteristics, and design considerations of key microwave devices, including Gunn diodes, IMPATT diodes, and Schottky diodes.
- To discuss the DC and high-frequency behavior of Bipolar Junction Transistors (BJTs), including their current-voltage relationships and performance limitations in microwave applications.

Course Outcomes (COs)

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

CO1: Explain the fundamental semiconductor physics including carrier concentration, recombination, and diffusion mechanisms.

CO2: Analyze the working, current–voltage characteristics, and capacitances of p–n junction diodes.

CO3: Describe the tunneling phenomenon in diodes and their application as amplifiers and oscillators.

CO4: Evaluate the performance of microwave and high-frequency devices such as Gunn, IMPATT, and Schottky diodes.

CO5: Discuss the current–voltage relations and frequency response of Bipolar Junction Transistors (BJTs) and their applications in microwave regions.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	3	3	3	3	2	2	3	1	1	2	1	1	2
CO2	3	3	2	3	2	3	2	3	3	2	1	2	1	1	2
CO3	3	3	2	3	3	3	2	2	3	1	1	2	1	1	2
CO4	3	3	2	3	2	3	2	3	3	2	1	2	1	1	2
CO5	3	3	2	3	2	3	2	3	3	2	1	2	1	1	2

1 = High Mapping

2 = Moderate Mapping

3 = Strong Mapping

Detailed Syllabus

Unit / Hours	Contents	Mapping with COs
Unit I / 9 hrs	Semiconductor Physics: Carrier concentration in intrinsic and extrinsic semiconductors; recombination processes; current density and continuity equations; decay of photo-excited carriers; steady-state injection; transient and steady-state diffusion processes.	CO1
Unit II / 9 hrs	P–N Junction Diode: Junction and diffusion capacitance, diode current–voltage equation, breakdown mechanisms, and temperature dependence of diode parameters. Varactor diode and principles of parametric conversion and amplification.	CO2
Unit III / 9 hrs	Tunnel Diode: Energy band diagram, V–I characteristics, negative resistance region, and applications as amplifier and oscillator.	CO3
Unit IV / 9 hrs	Microwave Diodes: Gunn diode – modes of operation, power and frequency performance. IMPATT diode – static and dynamic characteristics, small-signal analysis, negative conductance, device design, and performance. Schottky effect and Schottky diode principles.	CO4
Unit V / 9 hrs	Bipolar Junction Transistor (BJT): Current–voltage relations in active, cutoff, and saturation regions; microwave transistors; cutoff frequency; device geometry and performance characteristics.	CO5

Suggested Readings:

1. Streetman, B. G., & Banerjee, S. K. (2000). *Solid State Electronic Devices*. Prentice Hall, New Jersey.
2. Sze, S. M., & Ng, K. K. (2006). *Physics of Semiconductor Devices*. Wiley, New York.
3. Millman, J., & Halkias, C. C. (1991). *Electronic Devices and Circuits*. Tata McGraw Hill, New Delhi.
4. Ben G. Streetman. (1995). *Introduction to Semiconductor Devices*. Prentice-Hall of India, New Delhi.
5. Neudeck, G. W. (1989). *The PN Junction Diode: Semiconductor Fundamentals*. Addison-Wesley, USA.
6. Millman, J., & Grabel, A. (1987). *Microelectronics*. McGraw Hill, New York.

Course Title: LASER AND SPECTROSCOPY

Paper – III: ADVANCED ATOMIC SPECTROSCOPY

Course Code: PHY670

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To understand the quantum electrodynamic (QED) origins of the Lamb shift, including the concepts of vacuum fluctuations and self-energy, and its critical role in refining the hydrogen atomic model and testing QED.
- To develop the ability to analyze and interpret complex atomic spectra for many-electron atoms by applying formal methods like Breit's scheme and Hund's rules for deriving spectral terms of non-equivalent electrons.
- To explain the unique properties of Rydberg atoms and their highly excited states, and to explore their significance and applications in modern fields such as quantum computing and astrophysics.
- To evaluate and compare the underlying principles, capabilities, and applications of advanced spectroscopic techniques including ICP-OES, ICP-MS, PES, AES, and XRF for elemental and chemical analysis.
- To analyze the fundamental working principles, operational modes, and specific capabilities and limitations of high-resolution microscopy techniques such as SEM, TEM, AFM, STEM, and Fluorescence Microscopy.

Course Outcomes:

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

- **CO1:** Understand the quantum electrodynamic origins of the Lamb shift and its significance in refining the hydrogen atomic model.
- **CO2:** Analyze and interpret complex atomic spectra, including the derivation of spectral terms for elements with non-equivalent electrons using formal methods like Breit's scheme.
- **CO3:** Explain the properties and significance of Rydberg atoms and their states in modern atomic physics.
- **CO4:** Evaluate the principles, applications, and comparative advantages of advanced spectroscopic techniques like ICP-OES, ICP-MS, PES, AES, and XRF.
- **CO5:** Analyze the working principles, capabilities, and limitations of various high-resolution microscopy techniques such as SEM, TEM, AFM, and Fluorescence Microscopy.

Mapping of Course outcomes:

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	3	3	2	2	3	1	1	2	1	1	2
CO2	3	3	2	3	3	3	2	2	3	1	1	2	1	1	2
CO3	3	3	2	3	3	3	2	2	3	1	1	2	1	1	2
CO4	3	2	2	3	2	3	2	3	3	2	2	2	2	2	2

CO5	3	2	2	3	2	3	2	3	3	2	2	2	2	2	2
-----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping

Units/Hours	Contents	Mapping with Course Outcome
I/9	Lamb Shift and Hydrogen Spectrum: Quantum electrodynamic corrections to the Dirac solution, Concept of vacuum fluctuations and self-energy, Experimental observation of the Lamb shift in hydrogen, Significance in testing quantum electrodynamics (QED).	CO1
II/9	Complex Spectra and Their Interpretation: Analysis of spectra for many-electron atoms (Nitrogen, Oxygen, Manganese as examples), Hund's rules and term symbols for non-equivalent electrons, Alternation of multiplicities, Inversion of energy states and its causes.	CO2
III/9	Advanced Term Derivation and Rydberg States: Breit's scheme for systematic spectral term derivation, The concept of Rydberg atoms, Properties of Rydberg states (large size, high polarizability, long lifetime), Applications in quantum computing and astrophysics.	CO2, CO3
IV/9	Advanced Spectroscopic Techniques: Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES): Principle and applications, Inductively Coupled Plasma Mass Spectroscopy (ICP-MS): Principle and applications, Photo electron spectroscopy (PES): Surface and chemical analysis, Auger Electron Spectroscopy (AES): Elemental surface analysis, X-Ray Fluorescence Spectroscopy (XRF): Principle and quantitative analysis.	CO4

Units/Hours	Contents	Mapping with Course Outcome
V/9	High-Resolution Microscopy: Limitations of Optical and Electron Microscopes, Scanning Electron Microscopy (SEM): Principle, instrumentation, and image formation, Transmission Electron Microscopy (TEM): Principle and applications, Atomic Force Microscopy (AFM): Principle and operational modes, Scanning Tunneling Electron Microscopy (STEM): Principle, Fluorescence Microscopy: Principles and introduction to super-resolution techniques.	CO5

Suggested Readings:

1. Demtröder, W. (2010). *Laser Spectroscopy: Vol. 1 & 2*. Springer.
2. Svanberg, S. (2004). *Atomic and Molecular Spectroscopy: Basic Aspects and Practical Applications*. Springer.
3. Thorne, A., Litzen, U., & Johansson, S. (1999). *Spectrophysics: Principles and Applications*. Springer.
4. Cowan, R. D. (1981). *The Theory of Atomic Structure and Spectra*. University of California Press.
5. Goldstein, J., et al. (2017). *Scanning Electron Microscopy and X-Ray Microanalysis*. Springer.
6. Briggs, D., & Grant, J. T. (Eds.). (2003). *Surface Analysis by Auger and X-Ray Photoelectron Spectroscopy*. IM Publications.

Course Title: LASER AND SPECTROSCOPY

Paper – IV: IR & RAMAN SPECTRA OF POLYATOMIC MOLECULES

Course Code: PHY671

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To enable students to classify polyatomic molecules into their correct point groups by systematically identifying and applying symmetry elements and operations.
- To analyze the rotational spectra of linear and symmetric top polyatomic molecules, including the interpretation of spectral structure influenced by nuclear spin statistics and symmetry properties.

- To derive the normal modes of vibration for polyatomic molecules using coordinate transformations and to correlate these modes with their activity in infrared and Raman vibrational spectra.
- To develop the ability to interpret complex vibrational phenomena such as Fermi resonance, inversion, and torsional oscillations, and to apply functional group analysis for molecular identification using IR and Raman spectroscopy.
- To analyze the interaction between rotational and vibrational motions in polyatomic molecules, including the effects of Coriolis coupling, and to interpret the resulting complex structure in IR and Raman spectra.

Course Outcomes:

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

- **CO1:** Classify molecules into their respective point groups by identifying symmetry elements and operations.
- **CO2:** Analyze the rotational spectra of linear and symmetric top polyatomic molecules, including the influence of nuclear spin and statistics on spectral structure.
- **CO3:** Derive the normal modes of vibration for polyatomic molecules and correlate them to their IR and Raman vibrational spectra.
- **CO4:** Interpret complex spectral phenomena such as Fermi resonance, inversion, and torsional oscillations, and apply functional group analysis for molecular identification.
- **CO5:** Analyze the interaction between rotation and vibration in polyatomic molecules, including the effects of Coriolis coupling on the IR and Raman spectra.
- **Mapping of Course outcomes:**

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	2	2	3	1	1	2	1	1	2
CO2	3	3	3	3	3	3	2	2	3	1	1	2	1	1	2
CO3	3	3	2	3	3	3	2	2	3	2	1	2	1	1	2
CO4	3	3	2	3	3	3	2	2	3	2	1	2	1	1	2
CO5	3	3	2	3	3	3	2	2	3	2	1	2	1	1	2

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Molecular Symmetry: Symmetry Elements and Symmetry Operations, Introduction to Point Groups, Systematic Classification of Molecules into Point Groups (with examples).	CO1
II/9	Rotational Spectroscopy of Polyatomics: Rotation and Rotational Spectra of Linear and Symmetric Top Polyatomic Molecules, Energy Levels and Symmetry Properties, Influence of Nuclear Spin and Statistics on Spectral Intensity, Rotational Structure in Far-IR Spectra, Rotational Structure in Raman Spectra & Alteration of Intensity.	CO2
III/9	Vibrational Spectroscopy Fundamentals: Vibrational Motion of Polyatomic Molecules, Motion in Cartesian Coordinates and Mass-Weighted Cartesian Coordinates, Concept of Normal Coordinates and Normal Modes of Vibration, Vibrational Energy Expression, Fundamentals of Infra-red and Raman Vibrational Spectra.	CO3
IV/9	Advanced Vibrational Phenomena & Analysis: Fermi Resonance, Concept of Several Potential Minima and Inversion (e.g., in Ammonia Molecule), Torsional Oscillations, Active and Inactive IR and Raman Fundamentals, Functional Group Analysis using IR and Raman Spectroscopy.	CO4
V/9	Rotation-Vibration Interaction: Interaction of Rotation and Vibration in Polyatomic Molecules, Rotation-Vibration Spectra of Linear Polyatomic Molecules, Energy Levels and Symmetry Properties, Coriolis Interaction and its Spectral Consequences, Detailed Analysis of IR and Raman Spectra of Linear Polyatomic Molecules.	CO5

Suggested Readings:

1. Banwell, C. N., & McCash, E. M. (2008). *Fundamentals of Molecular Spectroscopy*. Tata McGraw-Hill.
2. Colthup, N. B., Daly, L. H., & Wiberley, S. E. (2015). *Introduction to Infrared and Raman Spectroscopy*. Academic Press.
3. Cotton, F. A. (2009). *Chemical Applications of Group Theory*. Wiley.
4. Herzberg, G. (2010). *Molecular Spectra and Molecular Structure: Vol. II - Infrared and Raman Spectra of Polyatomic Molecules*. Krieger Publishing Company.
5. Hollas, J. M. (2004). *Modern Spectroscopy*. John Wiley & Sons.

Course Title: X-RAYS AND ION BEAM**Paper - III: GEOMETRICAL X-RAY DIFFRACTION**

Course Code: PHY672

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To establish a foundational understanding of crystallographic symmetry, diffraction geometry, and the reciprocal lattice, including the influence of temperature on diffraction phenomena through the Debye-Waller factor.
- To apply the principles of X-ray scattering to calculate diffraction intensities from crystals, incorporating atomic scattering factors and structure factors, and to analyze the diffraction properties of both mosaic and perfect crystals.
- To evaluate the principles and methodologies of major single crystal and powder diffraction techniques for data collection and to understand the fundamental approaches to solving the phase problem in crystal structure determination.
- To analyze the theory of diffuse X-ray scattering and apply it to probe the structure of non-crystalline materials, including gases, liquids, and amorphous solids, using techniques like the radial distribution function.
- To compare and contrast the principles and applications of X-ray, electron, and neutron diffraction techniques, and to apply them to study specialized phenomena such as order-disorder transitions in alloys and nanostructures.

Course Outcomes:

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

- **CO1:** Understand the fundamental concepts of crystallographic symmetry, diffraction geometry, and the influence of temperature on diffraction phenomena.
- **CO2:** Apply the principles of X-ray scattering to calculate diffraction intensities and analyze the properties of mosaic and perfect crystals.

- **CO3:** Evaluate different single crystal and powder diffraction methods for data collection and understand the principles of solving the phase problem in crystal structure determination.
- **CO4:** Analyze the diffuse scattering of X-rays to probe the structure of non-crystalline materials like gases, liquids, and amorphous solids.
- **CO5:** Compare and contrast various diffraction techniques (X-ray, electron, neutron) and apply them to study specialized phenomena like order-disorder transitions and nanostructures.
- **Mapping of Course outcomes:**

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Fundamentals of Crystallography and Diffraction: Symmetries and Classification of Crystals, Point Groups and Space Groups, Bragg's Law, Reciprocal Lattice Concept and Construction, Ewald Construction, Laue Equations, Temperature Effects (Debye-Waller Factor).	CO1
II/9	Theory of X-Ray Scattering: Scattering of X-Rays by a Single Electron, Lorentz and Polarization Factors, Atomic Scattering Factor, Diffraction by a Composite	CO2

Units/Hours	Contents	Mapping with Course Course Outcome
	Lattice and Structure Factor, Integrated Reflection from Mosaic and Perfect Crystal Models.	
III/9	Experimental Methods & Structure Solution: Powder Diffraction Method, Laue Method, Rotation and Oscillation Methods, Weissenberg Method, Introduction to Crystal Structure Analysis, Fourier Method and Electron Density Maps, The Phase Problem, Patterson Function for Heavy Atom Location.	CO3
IV/9	Diffuse Scattering and Non-Crystalline Materials: Theory of Diffuse Scattering of X-Rays, Scattering by Gases (Radial Distribution Function), Scattering by Liquids, Scattering by Polymers and Amorphous Materials.	CO4
V/9	Specialized Diffraction Techniques & Phenomena: Small-Angle X-Ray Scattering (SAXS), Principles of Electron Diffraction and Neutron Diffraction, Comparison with X-Ray Diffraction, X-Ray Study of Order-Disorder Phenomena in Alloys.	CO5

Suggested Readings:

1. Cullity, B. D., & Stock, S. R. (2014). *Elements of X-Ray Diffraction*. Pearson Education.
2. Warren, B. E. (1990). *X-Ray Diffraction*. Dover Publications.
3. Guinier, A. (1994). *X-Ray Diffraction: In Crystals, Imperfect Crystals, and Amorphous Bodies*. Dover Publications.
4. Stout, G. H., & Jensen, L. H. (1989). *X-Ray Structure Determination: A Practical Guide*. Wiley.
5. Als-Nielsen, J., & McMorrow, D. (2011). *Elements of Modern X-Ray Physics*. Wiley.

Course Title: X-RAYS AND ION BEAM

Paper – IV: ION BEAMS INDUCED MODIFICATION AND CHARACTERIZATION TECHNIQUES

Course Code: PHY673

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To introduce the fundamental theories of ion energy loss in solids, including the mechanisms of electronic and nuclear stopping, and to explain advanced models such as the Thermal Spike and Coulomb Explosion.
- To enable students to apply Monte-Carlo simulation tools (SRIM/TRIM) for predicting ion range and radiation damage, and to understand subsequent ion-induced phenomena like diffusion, mixing, and phase formation.
- To evaluate the underlying principles, experimental setups, and data interpretation methods for major ion beam analysis techniques, including RBS, Channeling, ERDA, NRA, and PIXE for comprehensive material characterization.
- To equip students with the knowledge to design and analyze ion beam processes for fabricating and modifying advanced electronic devices, such as heterojunctions and artificially structured materials with tailored properties.
- To assess the effects of ion irradiation on the structure and properties of specialized functional materials like polymers and high-temperature superconductors, focusing on defect engineering for tuning specific characteristics.

Course Outcomes:

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

- **CO1:** Analyze the fundamental theories of ion energy loss in solids, including electronic and nuclear stopping, and models like Thermal Spike and Coulomb Explosion.
- **CO2:** Apply Monte-Carlo simulation tools (SRIM/TRIM) to predict ion range and damage, and understand ion-induced phenomena like radiation damage, diffusion, and phase formation.
- **CO3:** Evaluate the principles and applications of major ion beam analysis techniques (RBS, Channeling, ERDA, NRA, PIXE) for material characterization.
- **CO4:** Design and analyze ion beam processes for fabricating and modifying advanced electronic devices, including heterojunctions and artificially structured materials.
- **CO5:** Assess the effects of ion irradiation on the properties of specialized materials like polymers and high-temperature superconductors, including defect engineering for property tuning.
- **Mapping of Course outcomes:**

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping
-

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Fundamental Ion-Solid Interactions: Energy Loss of MeV Ions in Solids: Interaction of a particle with a free electron gas, Local Density Approximation in stopping power theory, Electronic stopping cross-section, Nuclear and Electronic Energy Loss. Theories of Energy Transfer: Thermal Spike, Coulomb Explosion, Lateral Mass Transport.	CO1
II/9	Ion Implantation & Radiation Effects: Simulation of Range Distribution by Monte-Carlo Methods (SRIM/TRIM), Ion Implantation Processes, Radiation Damage and Structural Change, Ion Beam Mixing, Radiation Enhanced Diffusion, Diffusion by Vacancies, Self-Diffusion and Impurity Diffusion, Impurity Incorporation, Silicide Formation.	CO2
III/9	Ion Beam Characterization Techniques: Rutherford Backscattering Spectrometry (RBS) and Channeling, Elastic Recoil Detection Analysis (ERDA), Nuclear	CO3

Units/Hours	Contents	Mapping with Course Course Outcome
	Reaction Analysis (NRA), Particle-Induced X-ray Emission (PIXE). Principles, experimental setup, and data interpretation.	
IV/9	Ion Beams in Device Fabrication: Amorphous Superstructure and Hetero-junctions, Band Discontinuities and Local Structure, Ion-Induced Amorphous to Single Crystal Transition in Silicon, Artificially Structured Materials, Buried Layers and Band Structural Engineering for New Functional Devices.	CO4
V/9	Ion Modification of Functional Materials: Ion Irradiation of Polymers. Ion Modification of Superconductors: Special features of the superconducting state - magnetization $M(H)$, specific heat, the energy gap. High-Tc Superconductors (HTSC): columnar defects and modification of superconducting properties. Conditions leading to formation of defects using ions for tuning Band Gaps, Photoluminescence and Iono-luminescence properties.	CO5

Suggested Readings:

1. Nastasi, M., Mayer, J. W., & Hirvonen, J. K. (2014). *Ion-Solid Interactions: Fundamentals and Applications*. Cambridge University Press.
2. Ziegler, J. F., Biersack, J. P., & Ziegler, M. D. (2008). *SRIM - The Stopping and Range of Ions in Matter*. SRIM Co.
3. Ohring, M. (2002). *Materials Science of Thin Films*. Academic Press.
4. Feldman, L. C., & Mayer, J. W. (1986). *Fundamentals of Surface and Thin Film Analysis*. North-Holland.
5. Townsend, P. D., Chandler, P. J., & Zhang, L. (1994). *Optical Effects of Ion Implantation*. Cambridge University Press.

Course Title: NON-LINEAR OPTICS

Paper – III: RESONANT INTERACTION OF ATOMS WITH RADIATION – I

Course Code: PHY674

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To analyze different mechanisms of spectral line broadening and to apply the semi-classical theory, using the rotating wave approximation, to model a two-level atom via the pseudo-spin vector formalism on the Bloch sphere.
- To formulate the Optical Bloch Equations, provide a physical interpretation of their components, distinguish them from classical descriptions, and incorporate phenomenological decay constants (T_1 and T_2).
- To solve the Optical Bloch Equations for both steady-state and time-dependent scenarios and apply these solutions to understand transient coherent phenomena such as optical nutation and adiabatic following.
- To model the mutual interaction between light and matter by coupling the Maxwell wave equation with the Optical Bloch Equations, and to explain the physical principles underlying self-induced transparency and soliton propagation.
- To understand the fundamental principles of the McCall-Hahn Area Theorem and the theory behind the photon echo phenomenon as a method for recovering lost coherence in inhomogeneously broadened systems.

Course Outcomes:

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

- **CO1:** Analyze different line-broadening mechanisms and apply the semi-classical theory with the rotating wave approximation to model a two-level atom using the pseudo-spin vector formalism.
- **CO2:** Formulate and interpret the Optical Bloch Equations, distinguishing between classical and semi-classical descriptions, and incorporate decay constants phenomenologically.
- **CO3:** Solve the Optical Bloch Equations for specific cases and apply the solutions to understand transient coherent phenomena like optical nutation and adiabatic following.
- **CO4:** Model the mutual interaction of light and matter by coupling the Maxwell and Optical Bloch Equations, and explain the concept and consequences of self-induced transparency.
- **CO5:** Understand the fundamental principles behind the McCall-Hahn Area Theorem and the photon echo phenomenon for recovering lost coherence in inhomogeneously broadened systems.
- **Mapping of Course outcomes:**

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Fundamentals of Line Broadening and Two-Level Atoms: Homogeneous and Inhomogeneous Broadenings, Semi-classical Theory of Interactions of Two-Level Atoms with Radiation, Rotating Wave Approximation, Description by a Pseudo-spin Vector on the Bloch Sphere.	CO1
II/9	The Optical Bloch Equations: Derivation and Physical Interpretation of the Optical Bloch Equations, Comparison of Classical and Semi-classical Descriptions, Elementary Ideas about Area of Pulses, Rabi Solution of Optical Bloch Equations, Phenomenological Introduction of Decay Constants (T1 and T2).	CO2
III/9	Solutions and Applications of the Bloch Equations: Steady-state and Time-dependent Solutions of the Optical Bloch Equations, Elementary Applications, Concepts of Optical Nutation and Adiabatic Following.	CO3

Units/Hours	Contents	Mapping with Course Course Outcome
IV/9	Coupled Light-Matter Dynamics: Coupled Maxwell and Optical Bloch Equations, The Factorization Assumption, Physical Principles and Elementary Ideas about Self-Induced Transparency and Soliton Propagation.	CO4
V/9	Advanced Coherent Phenomena: Elementary ideas about the McCall-Hahn Area Theorem, Theory and Mechanism of Photon Echo for reversing inhomogeneous dephasing, Directionality and Applications of the Photon Echo.	CO5

Suggested Readings:

1. Boyd, R. W. (2020). *Nonlinear Optics*. Academic Press.
2. Meystre, P., & Sargent, M. (2007). *Elements of Quantum Optics*. Springer.
3. Loudon, R. (2000). *The Quantum Theory of Light*. Oxford University Press.
4. Allen, L., & Eberly, J. H. (1987). *Optical Resonance and Two-Level Atoms*. Dover Publications.
5. Shen, Y. R. (2002). *The Principles of Nonlinear Optics*. Wiley-Interscience.

Course Title: NON-LINEAR OPTICS

Paper – IV: RESONANT INTERACTION OF ATOMS WITH RADIATION– II

Course Code: PHY675

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To formulate the problem of a two-level atom using the formalism of atomic spin operators and to introduce the concept of geometric phases, specifically Berry's Phase, in quantum systems.
- To apply Dicke's model for describing collective atomic states and to represent these states and their operators using Holstein-Primakoff and two-boson transformations.

- To understand the fundamental concept of quantum entanglement in two-qubit systems, including the properties of Bell states, and to explain its application in quantum information protocols like quantum teleportation.
- To utilize the different pictures of quantum mechanics (Schrödinger, Heisenberg, Interaction) and to rigorously derive the atom-field interaction Hamiltonian, including the justification for the dipole and rotating wave approximations.
- To analyze fundamental phenomena in quantum electrodynamics, including the Weisskopf-Wigner theory of spontaneous emission, a qualitative treatment of the Lamb Shift, and the theory of superradiance from a collection of atoms.

Course Outcomes:

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

- **CO1:** Formulate the two-level atom problem using atomic spin operators and analyze geometric phases like Berry's Phase in quantum systems.
- **CO2:** Apply Dicke's model of collective atomic states and represent them using Holstein-Primakoff and two-boson transformations.
- **CO3:** Understand the concept of quantum entanglement in two-qubit systems and explain its application in protocols like quantum teleportation.
- **CO4:** Utilize different pictures of quantum mechanics (Schrödinger, Heisenberg, Interaction) and derive the atom-field interaction Hamiltonian under the dipole and rotating wave approximations.
- **CO5:** Analyze fundamental quantum electrodynamics phenomena including spontaneous emission (Weisskopf-Wigner), the Lamb Shift, and Super-radiance.
- **Mapping of Course outcomes:**

Course Outcomes	PS O1	PS O2	PS O3	PS O4	PS O5	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping
-

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Advanced Two-Level Atom Formalism: Two-Level Model of Atoms, Atomic Spin Operators and States and their properties, Rotations in Atomic Spin Space, Elementary Ideas about Geometric Phases and Berry's Phase.	CO1
II/9	Collective Atomic Behavior: Dicke's Collective Atom Operators and States, Degeneracy of Dicke States of an Assembly of Atoms, Holstein-Primakoff and Two-Boson Modes Representations of Dicke Operators and States.	CO2
III/9	Quantum Entanglement and Information: Elementary Ideas about Entanglement of Two Two-Level Systems, Bell States, their Properties and Use in Quantum Teleportation Protocol.	CO3
IV/9	Formalisms of Light-Matter Interaction: Schrödinger, Heisenberg and Interaction Pictures. Derivation of the Hamiltonian for Interaction of an Atom with Radiation. Relative Contributions of $\mathbf{p} \cdot \mathbf{A}$ and $\mathbf{A}^2$ terms, Dipole Approximation, Rotating Wave Approximation.	CO4
V/9	Quantum Electrodynamics Phenomena: Weisskopf-Wigner Theory of Spontaneous Emission, Wigner's Qualitative Treatment of Lamb Shift, Theory of Superradiance and Cooperative Emission from a Collection of Atoms.	CO5

Suggested Readings:

1. Loudon, R. (2000). *The Quantum Theory of Light*. Oxford University Press.
2. Meystre, P., & Sargent, M. (2007). *Elements of Quantum Optics*. Springer.

3. Scully, M. O., & Zubairy, M. S. (1997). *Quantum Optics*. Cambridge University Press.
4. Agarwal, G. S. (2013). *Quantum Optics*. Cambridge University Press.
5. Dicke, R. H. (1954). "Coherence in Spontaneous Radiation Processes". *Physical Review*. (Seminal Paper for Study)
6. Nielsen, M. A., & Chuang, I. L. (2010). *Quantum Computation and Quantum Information*. Cambridge University Press. (For Unit III)

Course Title: NUCLEAR AND PARTICLE PHYSICS

Paper – III: ADVANCED NUCLEAR AND PARTICLE PHYSICS

Course Code: PHY676

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To analyze the principles of radiation detection, apply statistical methods for data quality assessment, and interpret complex decay schemes using advanced spectroscopic techniques like gamma detector arrays and coincidence methods.
- To differentiate between compound nucleus and pre-equilibrium reaction models, and to analyze nuclear reaction cross-sections, resonance phenomena, and the effects of level density in statistical reactions.
- To apply the theories of direct reactions, including the Plane Wave Born Approximation (PWBA), and the optical model to problems in nuclear spectroscopy and to calculate average reaction cross-sections.
- To evaluate the unique characteristics of heavy-ion induced reactions, including the analysis of elastic scattering using the diffraction model and the principles of Coulomb excitation.
- To examine the novel properties of exotic nuclei at the limits of stability, including halo structures, new decay modes, and the role of Radioactive Ion Beam (RIB) facilities in their production and study.

Course Outcomes:

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

- **CO1:** Analyze the principles of radiation detection, apply statistical methods for data quality assessment, and interpret complex decay schemes using advanced spectroscopic techniques.
- **CO2:** Differentiate between compound nucleus and pre-equilibrium reaction models, and analyze nuclear reaction cross-sections, resonance phenomena, and level density effects.

- **CO3:** Apply the theories of direct reactions and the optical model to nuclear spectroscopy and calculate average reaction cross-sections.
- **CO4:** Evaluate the unique characteristics of heavy-ion induced reactions, including elastic scattering and Coulomb excitation, using appropriate theoretical models.
- **CO5:** Examine the properties of exotic nuclei at the limits of stability, including their novel structures and decay modes, and understand the role of Radioactive Ion Beam (RIB) facilities in their study.
- **Mapping of Course outcomes:**

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
- 2 = Moderate Mapping
- 3 = Strong Mapping

Units/Hours

Contents

Mapping
with
Course
Course
Outcome

I/9

Experimental Techniques and Data Analysis: Interaction of Charged Particles and Radiation with Matter, Experimental Techniques in Particle and Gamma Ray Spectroscopy, Gamma Detector Arrays, Coincidence Method, Decay Schemes, Counters, Statistics of Counting (Poisson and Gaussian Distribution), Statistical Quality of Data, Chi-Square Test.

CO1

Units/Hours	Contents	Mapping with Course Course Outcome
II/9	Compound Nucleus and Statistical Reactions: Compound Nucleus Model, Resonance Reactions and Level Density, Decay of the Compound Nucleus, Reaction Cross-Section, Entrance Channel Effect, Statistical Theory, Pre-Equilibrium Model.	CO2
III/9	Direct Reactions and the Optical Model: Direct Reaction Mechanisms, Plane Wave Born Approximation (PWBA), General Theory of Direct Reactions, Examples of Direct Reactions, Nuclear Spectroscopy from Direct Reactions, Theory of Average Cross-Section, Optical Model.	CO3
IV/9	Heavy-Ion Reaction Dynamics: Heavy Ion Induced Nuclear Reactions, Features of Medium and Low Energy Heavy Ion Elastic Scattering, Diffraction Model, Coulomb Excitation.	CO4
V/9	Physics of Exotic Nuclei: Nuclear Structure at the Extremes of Stability, Proton and Neutron Drip Lines, Nuclear Halos, Neutron Skins, Proton Rich Nuclei, Decay Modes of Exotic Nuclei, Radioactive Ion Beams (RIB) as a New Experimental Technique.	CO5

Suggested Readings:

1. Krane, K. S. (1987). *Introductory Nuclear Physics*. Wiley.
2. Wong, S. S. M. (2008). *Introductory Nuclear Physics*. Wiley-VCH.
3. Hodgson, P. E., Gadioli, E., & Gadioli Erba, E. (1997). *Introductory Nuclear Physics*. Oxford University Press.
4. Bertulani, C. A. (2007). *Nuclear Physics in a Nutshell*. Princeton University Press.
5. Lilley, J. (2001). *Nuclear Physics: Principles and Applications*. Wiley.
6. Leo, W. R. (1994). *Techniques for Nuclear and Particle Physics Experiments: A How-To Approach*. Springer.

Course Title: NUCLEAR AND PARTICLE PHYSICS

Paper – IV: ADVANCED NUCLEAR AND PARTICLE PHYSICS

Course Code: PHY677

L–T–P–Cr: 3–1–0–4

Total Hours: 45

Course Objectives

- To apply the formalism of relativistic kinematics, including Mandelstam variables and Lorentz invariant phase space, for calculating cross-sections in $2 \rightarrow 2$ scattering processes and decay widths for particle decays.
- To construct the Quantum Electrodynamics (QED) Lagrangian from the principle of gauge invariance and to calculate the cross-sections for fundamental QED processes such as electron-positron annihilation into muon pairs.
- To analyze the structure of the weak interaction, incorporating parity violation via the (V-A) theory, and to compute decay widths for key leptonic and semi-leptonic processes, introducing the concept of quark mixing via the Cabibbo angle.
- To describe the foundational concepts of strong interaction physics, including the evidence for quarks from deep inelastic scattering and the parton model, and to introduce the basic principles of Quantum Chromodynamics (QCD).
- To explain the unification of electromagnetic and weak interactions, the mechanism of spontaneous symmetry breaking via the Higgs field, and how this leads to mass generation for vector bosons and fermions, culminating in the prediction of neutral currents.

Course Outcomes:

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

- **CO1:** Apply the formalism of relativistic kinematics, including Mandelstam variables and Lorentz invariant phase space, to calculate cross-sections and decay widths for fundamental particle processes.

- **CO2:** Construct the QED Lagrangian, explain the principle of gauge invariance, and calculate the cross-section for elementary QED processes like Bhabha scattering and Muon pair production.
- **CO3:** Analyze the structure of the weak interaction, including parity violation and the (V-A) theory, and compute decay widths for leptonic and semi-leptonic processes, incorporating the Cabibbo angle.
- **CO4:** Describe the key concepts of modern particle physics, including the parton model, deep inelastic scattering, and the fundamental principles of Quantum Chromodynamics (QCD).
- **CO5:** Explain the unification of electromagnetic and weak interactions, the role of spontaneous symmetry breaking and the Higgs mechanism in generating particle masses, and the prediction of neutral currents.
- **Mapping of Course outcomes:**

Cours e Outco mes	PS O1	PS O2	PS O3	PS O4	PS O5	P O 1	P O 2	P O 3	P O 4	P O 5	P O 6	P O 7	P O 8	P O 9	PO 10
CO1	3	3	2	3	3	3	1	2	3	1		1		1	
CO2	3	3	3	3	3	3	1	2	3	1		1		1	
CO3	3	3	2	3	3	3	1	2	3	2		1		1	
CO4	3	3	3	3	3	3	1	2	3	2		1		1	
CO5	3	3	2	3	3	3	1	2	3	2		1		1	

- 1 = High Mapping
2 = Moderate Mapping
3 = Strong Mapping

Units/Hours	Contents	Mapping with Course Course Outcome
I/9	Relativistic Kinematics and Decay Rates: Basic Relativistic Kinematics, Mandelstam Variables (s, t, u), Lorentz Invariant Phase Space, Cross Section for $2 \rightarrow 2$	CO1

Units/Hours	Contents	Mapping with Course Course Outcome
	Scattering Processes, Decay Width for $1 \rightarrow 2$ and $1 \rightarrow 3$ Processes.	
II/9	Quantum Electrodynamics (QED): Lagrangian for Electron-Photon Interaction, Concept of Gauge Invariance, Calculation of Cross-Section for $e^+e^- \rightarrow \mu^+\mu^-$ (Muon Pair Production) and other $2 \rightarrow 2$ QED processes.	CO2
III/9	The Weak Interaction: Phenomenology of Weak Interaction, Parity Violation and the (V-A) Theory, Calculation of Amplitude and Decay Width for Pion Decay ($\pi^+ \rightarrow \mu^+\nu_\mu$) and Muon Decay ($\mu^- \rightarrow e^-\bar{\nu}_e\nu_\mu$), The Cabibbo Angle and Quark Mixing.	CO3
IV/9	Introduction to QCD and Deep Inelastic Scattering: Brief Overview of the Standard Model, Qualitative Introduction to Deep Inelastic Scattering (DIS), The Parton Model, Scaling Violations and the Evidence for Quarks, Basic Concepts of Quantum Chromodynamics (QCD) and Asymptotic Freedom.	CO4
V/9	Electroweak Unification and the Higgs Mechanism: Unification of Weak and Electromagnetic Interactions, Salam-Weinberg	CO5

Units/Hours	Contents	Mapping with Course Course Outcome
-------------	----------	--

Theory of Electroweak Unification,
Spontaneous Symmetry Breaking,
The Higgs Mechanism and Mass
Generation for W/Z Bosons and
Fermions, Prediction and Discovery
of Neutral Currents.

Suggested Readings:

1. Griffiths, D. (2008). *Introduction to Elementary Particles*. Wiley-VCH.
2. Halzen, F., & Martin, A. D. (1984). *Quarks and Leptons: An Introductory Course in Modern Particle Physics*. John Wiley & Sons.
3. Perkins, D. H. (2000). *Introduction to High Energy Physics*. Cambridge University Press.
4. Peskin, M. E., & Schroeder, D. V. (1995). *An Introduction to Quantum Field Theory*. Westview Press.
5. Cottingham, W. N., & Greenwood, D. A. (2007). *An Introduction to the Standard Model of Particle Physics*. Cambridge University Press.