THE UNIVERSITY OF BURDWAN

SYLLABUS OF ONE YEAR POSTGRADUATE PROGRAMME

IN

PHYSICS

Under

Curriculum and Credit Framework for Postgraduate Programme (CCFPP), as per N.E.P. 2020

w.e.f. 2027 – 2028

1- year PG Programme

Semester wise and Course wise Distribution of Credit & Marks under CCFPP as per NEP, 2020

OPTION- I: Coursework in the 1st Semester & Research Thesis/Project in the 2nd Semester

SEM	Course Type	Code& Level	Name of the Course	Credit	L – T - P	Marks	Marks Dist. Th. – Pr. - IA
I	Major/Core Course	**PG1 PHYS 1011 (500-599)**	Section I : Advanced Quantum Mechanics Section II : Advanced Mathematical Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1012 (500-599)**	Section I : Advanced Electrodynamics Section II : Advanced Computational Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1013 (500-599)**	Section I : Atomic Physics Section II : Particle Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1014 (500-599)**	Section I : Group Theory Section II : Nonlinear Dynamics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1015 (500-599)**	Advanced General Practical	4	0 – 0 - 4	50	0 – 40 – 10
	Total			**20**		**250**	
II	Research Thesis/ Project	**PG1 PHYS 2031 (500-599)**	Research Thesis/ Project	20	0- 0- 20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (4 credits, 50 Marks) & Viva-voce (4 Credits, 50 Marks,)- 8 Credits, 100 Marks
	Two-credit Compulsory Course	**PG1 PHYS 2041 (500-599)**	Community Engagement	(This shall not be taken into consideration in the calculation of SGPA and CGPA)			
	Total			**20**		**250**	

**** The course code PG1 PHYS 2031 will be offered to the students meeting the following criteria:**
(i) Minimum CGPA of 8.0 in UG (upto Semester VIII) and PG (Sem I)
(ii) Minimum attendance of 80% in PG (Semester I)
The final decision will be taken by the Departmental Committee subject to availability and feasibility of the courses.

OR

OPTION- II: Only Course- work in 1st&2nd Semesters

SEM	Course Type	Code & Level	Name of the Course	Credit	L – T - P	Marks	Marks Dist. Th. – Pr. - IA
I	Major/Core Course	**PG1 PHYS 1011 (500-599)**	Section I : Advanced Quantum Mechanics Section II : Advanced Mathematical Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1012 (500-599)**	Section I : Advanced Electrodynamics Section II : Advanced Computational Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1013 (500-599)**	Section I : Atomic Physics Section II : Particle Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1014 (500-599)**	Section I : Group Theory Section II : Nonlinear Dynamics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 1015 (500-599)**	Advanced General Practical	4	0 – 0 - 4	50	0 – 40 – 10
	Total			**20**		**250**	
II	Major/Core Course	**PG1 PHYS 2011 (500-599)**	Molecular Physics	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 2012 (500-599)**	Discipline Specific Elective I 1: Advanced Electronics-I 2: Astrophysics & Cosmology-I 3: Materials Science-I 4: Condensed Matter Physics-I 5: Nuclear & Particle Physics-I 6: Laser Physics-I	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 2013 (500-599)**	Discipline Specific Elective II 1: Advanced Electronics-II 2: Astrophysics & Cosmology- II 3: Materials Science- II 4: Condensed Matter Physics- II 5: Nuclear & Particle Physics- II 6: Laser Physics- II	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 2014 (500-599)**	Term Paper/ Project Work	4	4 – 0- 0	50	40 – 0 – 10
	Major/Core Course	**PG1 PHYS 2015 (500-599)**	Advanced General Practical	4	0 – 0 - 4	50	0 – 40 – 10

	Two-credit Compulsory Course	**PG1 PHYS 2041 (500-599)**	Community Engagement	(This shall not be taken into consideration in the calculation of SGPA and CGPA)			
	Total			**20**		**250**	

The following are the options for students for Discipline-centric Electives in Semester-II as per their choice:

Discipline Specific Elective I	**To be offered in Discipline Specific Elective II**
Advanced Electronics-I	Advanced Electronics-II
Astrophysics & Cosmology-I	Astrophysics & Cosmology-II
Materials Science-I	Materials Science-II
Condensed Matter Physics-I	Condensed Matter Physics-II
Nuclear & Particle Physics-I	Nuclear & Particle Physics-II
Laser Physics-I	Laser Physics-II

OR

OPTION- III: Only Research Thesis/ Project in 1st&2nd Semesters

SEM	Course Type	Code & Level	Name of the Course	Credit	L – T - P	Marks	Marks Dist. Th. – Pr. - IA
I	Research Thesis/ Project	**PG1 PHYS 1031 (500-599)**	Research Thesis/ Project	20	0-0-20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (4 credits, 50 Marks) & Viva-voce (4 Credits, 50 Marks,)-8 Credits, 100 Marks
Total				**20**		**250**	
II	Research Thesis/ Project	**PG1 PHYS 2031 (500-599)**	Research Thesis/ Project	20	0-0-20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (4 credits, 50 Marks) & Viva-voce (4 Credits, 50 Marks,)-8 Credits, 100 Marks
	Two-credit Compulsory Course	**PG1 PHYS 2041 (500-599)**	Community Engagement	(This shall not be taken into consideration in the calculation of SGPA and CGPA)			
Total				**20**		**250**	
Grand Total				**40**		**500**	

**** The course code PG1 PHYS 1031 and 2031 will be offered to the students meeting the following criteria:**
(i) Minimum CGPA of 8.0 in UG (upto Semester VIII)
(ii) Minimum attendance of 80% in UG (upto Semester VIII)
The final decision will be taken by the Departmental Committee subject to availability and feasibility of the courses.

OPTION- I: Course-work in the 1st Semester & Research Thesis/Project in the 2nd Semester

Course code: PG1PHYS1011 (Advanced Mathematical Physics & Advanced Quantum Mechanics)

COURSE OBJECTIVE: *The aim of this course is to introduce the students with the advanced mathematical techniques and a few topics of quantum mechanics.*

50 Hours

Section I: Advanced Mathematical Physics

1. Integral Transforms: Fourier, Laplace, Hankel and Mellin transforms, Inverse transforms, Convolution theorem, Solution of ordinary and partial differential equations by transform methods.

Discrete Transforms: Z transform, Inverse Z transform, Shifting property, Solution of difference equations using Z transform method, Convolution theorem.

2. Green's functions for ordinary and partial differential equations of mathematical physics, Integral equations, Fredholm and volterra equations of the first and second kinds, Solution of integral equations by using Integral transforms, Generating functions, Neumann series, Separable (degenerate) kernels methods, Hilbert – Schmidt theory.

3. Tensor analysis, Coordinate transformations, Scalars, Covariant and Contravariant tensors, Addition, subtraction, outer product, inner product and contraction, Symmetric and antisymmetric tensors, Quotient law, Metric tensor, Conjugate tensor, Length and angle between vectors, Associated tensors, Raising and lowering of indices.

Tensor calculus, Differentiation of a tensor, The Christoffel symbols and their transformation laws, Covariant derivative of tensors.

Section II: Advanced Quantum Mechanics

1. Time dependent perturbation theory, Harmonic perturbation, Fermi's golden rule, Adiabatic and sudden approximations.

2. Relativistic Quantum Mechanics: The Klein Gordon (KG) equation, Covariant notations, Free particle energy, Negative energy and negative probability density, KG equation in an electromagnetic field.

The Dirac equation, Probability density and current, Properties of the Dirac matrices, Dirac γ matrices, the continuity equation, Free particle at rest, Plane wave solutions, Interpretation of –ve energy solutions The Dirac particle in an external electromagnetic field, The non-relativistic limit of the Dirac equation and the magnetic moment of the electron, Covariant form of the Dirac equation, Lorentz covariance of the Dirac equation.

3. Quantum Dynamics: The equations of motion, the Schrödinger picture, the Heisenberg picture, the Interaction picture.

4. Identical Particles: The identity of particles, Spins and statistics, Exchange degeneracy, Symmetrization postulate, Wave function of a two-particle system, Wave function of many-particle system, Example.

5. Scattering theory: Scattering of a particle by a fixed centre of force, Scattering amplitude, Differential and total cross sections, Partial wave analysis for elastic scattering, Optical theorem, Scattering by a hard sphere, Scattering from a potential well, The Born approximation, The first Born approximation, Validity of the first Born approximation, Scattering from Yukawa and Coulomb potential.

6. Bell's theorem and Quantum Entanglement.

Books Recommended:

1. George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.
2. J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.
3. P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists
4. Quantum Mechanics by Claude Cohen-Tannnoudji, Bernard Diu, Franck Laloë (Vol I and II).
5. Quantum Mechanics Concepts and Applications, Second Edition by Nouredine Zettili.
6. Quantum Mechanics by V.K. Thankappan.
7. Problems and Solutions on Quantum Mechanics, Edited by Yung-Kuo Lim.
8. Relativistic Quantum Mechanics- Walter Greiner, Springer-Verlag
9. Advanced Quantum Mechanics – J.J. Sakurai, Addison-Wesley Publishing Company, Inc.
10. Relativistic Quantum Mechanics – J.D. Bjorken and S.D. Drell, McGraw-Hill, New York.

COURSE OUTCOME

The students will learn the fundamentals and the use of Fourier and Laplace transforms, their inverse transforms and convolution theorem. The student is expected to become familiar with the method of Green's function to solve linear differential equations with inhomogeneous term. They will get knowledge of how to find solutions of integral equations by using different methods. They will also get knowledge of the tensor analysis and tensor calculus for formulating and solving problems in areas of physics. The students will learn about the relativistic quantum mechanics, the branch that includes the special theory of relativity in quantum mechanics and different pictures of quantum dynamics. They will acquire knowledge of treating identical particles and scattering phenomenon

Course code: PG1PHYS1012 (Advanced Electrodynamics and Advanced Computational Physics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different theories and applications of advanced electrodynamics and train the students to perform advanced computational programming using different languages.*

50 Hours

Advanced Electrodynamics

Equation of continuity of current, Displacement current, Vector and scalar potentials, Maxwell's potential equations, Gauge transformations, Lorentz gauge and Coulomb gauge, solution of Maxwell equations using Greens function and delta function, electromagnetic wave propagation through vacuum and isotropic dielectric medium, Maxwell's equations in a charge free and non-conducting simple dielectric. Wave equation in a conductor.

Lineard-Wiechart potentials, Fields of a uniformly moving charge, Fields of an accelerated charge: Fields, radiation (power) and angular distribution from a charge at low velocity (non-relativistic), radiation (power) from a charge at linear motion and circular motion, frequency spectrum from linearly accelerated charge, Bremsstrahlung-Cerenkov radiation. Radiation from a localised oscillating charges, near and far zone field, magnetic dipole radiation, quadruple radiation, Radiation reaction from energy conversation: Abraham-Lorentz theory, self-force. Lorentz transformations of observables: Transformations of electric and magnetic fields, Covariance and contravariance, Examples of 4-vectors: x, del, p, J, A, u.

Section II: Advanced Computational Physics

Introduction to Python programming: The Python Interpreter, Python console, Jupyter and python IDEs; Setting up and using python on GNU/Linux, Windows and Android operating systems; Simple Input and Output; Variables; Mathematical Operators; list, string, tuple, set, dictionary; Control flow and decision control: logical loop structure; Functions and lambdas; Object and class; Files: reading and writing. Python namespaces, installation, design and import of modules in python.

Scientific Computing in Python: Introduction to the Numerical Python (numpy), Scientific Python (scipy), and matplotlib modules. Numpy arrays; Initialization and basic operations; resizing; slicing of arrays; array as a matrix; 2D plotting with matplotlib; plot with external data. Curve-fitting with scipy, linear algebra with numpy. Solution to linear systems of equations (electrical circuit example), eigenvalue problem (anharmonic oscillator example).

Ordinary Differential Equations: initial Value problem and boundary value problem. Simple Euler and Runge-Kutta methods. Application in physics problems: damped harmonic oscillator, forcing and resonance; self sustained oscillation (van der Pol oscillator, Lorenz oscillator); visualization in phase space. Partial Differential Equations:

Laplace and Wave equations. Schrödinger equation and solutions to the eigenvalue problem for simple systems.

Books Recommended:

1. Marion- Classical Electrodynamics
2. Jackson- Classical Electrodynamics
3. Panofsky & Phillips- Classical Electrodynamics
4. Chen- Plasma Physics
5. Griffith-Electrodynamics
6. Numerical Python: Scientific Computing and Data Science Applications with Numpy, SciPy and Matplotlib, R. Johansson, 2019, Apress.
7. Computational Physics: Problem Solving with Python, 3rd Edition, Rubin H. Landau, Manuel J Páez, Cristian C. Bordeianu, 2015, Wiley.
8. Scientific Computing in Python, Abhijit Kar Gupta, Techno world, 2019.
9. Let Us Python, 2nd Edition, Y. Kanetkar, A. Kanetkar, 2020, BPB Publications.
10. Computational Physics, N.J. Giordano, 1997, Prentice-Hall.
11. Python and matplotlib essentials for scientists and engineers, Matt A. Wood, 2015, Morgan and Claypool Publishers.
12. Introducing Python: Modern Computing in Simple Packages, B. Lubanovic, 2015, O'Reilly Media, Inc.

COURSE OUTCOME

On completion of the course, the student should be able to:

- The fundamental of the Electrodynamics which deals with the LW potentials, radiation emitted by a charged particle in linear as well as in circular path and its applications.
- learn about Bremmstrahlung-Cerenkov Radiation
- Translate a theoretical or algorithmic model into code that enables computation, logically subdivide a computational model into a set of manageable computational tasks, and organize their code accordingly, choose among computational algorithms and computational tools to produce a solution, debug, test, and validate computational models, and extract physical insight from a computation.
- Use the Python programming language to numerically solve physics problems, focussing on the use of Python's numeric modules SciPy (Scientific Python), Numpy (Numerical Python), and graphics module Matplotlib (MATLAB-like Plotting Library).
- Apply Monte Carlo simulations, curve-fitting and interpolation of datasets, numerically solve systems of nonlinear equations, ordinary differential equations, multiple integrals, perform computational linear algebra, solve optimization problems, perform signal analysis using Fast Fourier Transforms etc

- Formulate and computationally solve any tractable problem in physics,

Course code: PG1PHYS1013 (Atomic Physics and Particle Physics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different advanced theories and phenomenona of atomic physics and particle physics.*

50 Hours

Section I: Atomic Physics

1. General discussion on one electron atoms, hydrogen and hydrogen-like systems, Degeneracy and spectra, Quantum defect, Fine Structure - Relativistic effects, Spin Orbit interaction, Lamb shift,
2. Spectra of divalent atoms: Approximations, Singlet and triplet states.
3. Many electron atoms. Hamiltonian, Approximations. L-S and j-j coupling, complex spectra, equivalent and non-equivalent electrons Hunds Rule and its applications
4. Effect of magnetic field on the above spectra, Zeeman and Paschen-Back effects.
5. Hyperfine structure in spectra of monovalent atoms, origin of X-rays spectra,
6. Laser in Spectroscopy:

(i) Absorption spectroscopy, (ii) excitation spectroscopy, (iii) ionization spectroscopy, (iv) saturation spectroscopy, (iv) photo acoustic spectroscopy, (v) opto-galvanic spectroscopy, Doppler-free spectroscopy, Tera Hertz spectroscopy with innovative applications.

Section II: Particle Physics

Radioactive decay: Basic ideas of alpha, beta and gamma decays. Gamma emission & kinematics, multipolarity and selection rules.

Elementary particles and their interactions:

A brief historical development; Classification of elementary particles; antiparticles and crossing symmetry; strange and resonance particles; fundamental interactions: typical strengths, range, time-scales; Feynman diagrams; Symmetries and conservation laws; Charge conjugation, Parity and Time reversal; G-parity; CPT theorem; CP violation in K^0 decay.

Weak interactions

Leptonic, semi-leptonic and non-leptonic interactions; beta spectrum and energetics; Fermi's theory of beta decay; Coulomb correction and Fermi-Kurie plot; allowed and forbidden transitions, selection rules; Non-conservation of parity in beta decay: τ-θ paradox, Wu's experiment; detection of the neutrino and its helicity; Goldhaber's experiment.

Strong interactions

SU(2) and SU(3) symmetry (qualitative); Gell-Mann–Nishijima relation; Symmetry classification of elementary particles (eightfold way): baryon and meson octet and decuplet; discovery of Ω^- baryon; Quark model and SU(3) flavor symmetry; charm, beauty and truth, idea of color; quark-confinement and asymptotic freedom.

Recommended books

1. Physics of Atoms and Molecules --- B. H. Bransden and C. J. Joachin (2^{nd} Ed), Pearson, 2003
2. Basic Atomic and Molecular Spectroscopy ---- J. M. Hollas, RSC Publishing, 2002
3. Spectra of Atoms and Molecules, Peter Bernath, 2^{nd} Ed, Oxford University Press, 2005
4. Introduction to Atomic Spectroscopy: H. E. White, Dover Publication, 1934
5. Atomic and Laser Spectroscopy: Allan Corney, Clarendon Press, Oxford.
6. Laser in Chemistry- D L Andrew
7. Modern Particle Physics-Mark Thompson, (Cambridge University Press).
8. Introduction to High Energy Physics-D H Perkins, (Cambridge University Press).
9. Introduction to elementary particles-D J Griffiths, (Wiley, 2008).
10. Quarks and Leptons: An introductory course in modern particle physics - F. Halzen and A.D. Martin (John Wiley & Sons)

COURSE OUTCOME

This course gives a thorough account of the processes occurring at the atomic level. Both experimental and theoretical approaches are discussed at length. The students will have a detailed understandings of the basic processes (at the electronic level) occurring inside an atom, when it is isolated as well as when it is under a force field. Various spectroscopic techniques in the syllabus will help them in a long way to enter into research arena as well as in industrial sectors involving R&D in various fields. In addition to the completion of this course, students should be able to:

- Understand the fundamental constituents of matter and their interactions.
- Explain the development of particle physics from hadrons to the Standard Model.
- Apply symmetry principles and conservation laws to particle interactions.
- Explain symmetry principles in particle physics.

The basic knowledge about elementary particles and interactions will be useful for the students for future theoretical or experimental research in high energy physics.

Course code: PG1PHYS1014 (Group Theory and Non-linear Dynamics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different methods and applications of group theory and non-linear dynamics.*

40 Hours

Section I: Group Theory

1. Abstract group theory:

Definition. Group axioms. Finite and infinite groups, Nature of a group, Rearrangement theorem. Group multiplication table. Subgroups and Cosets. Lagrange's theorem. Order of an element. Conjugate elements and classes. Cyclic and other distinct groups. Permutation groups. Invariant subgroups, factor groups. Generators. Isomorphism and homomorphism. Illustrations with point symmetry groups

2.**Representation theory**.

Definition, Faithful and unfaithful representations. Reducible and irreducible representations. Schur's lemmas, Great orthogonality theorem and its geometrical interpretation. Character. First and second orthogonality theorems of characters and its geometrical interpretation. Regular representation, celebrated theorem and its implication. Construction of character tables of simple groups.

3.**Continuous group**

Infinite groups. Discrete and continuous groups. Lie groups. Axial rotation group SO(2). Rotation group SO(3). Special Unitary groups SU(2) and SU(3) and their application in Physics.

4. **Application in Physics**

Group of Schrödinger equations and degeneracy, Applications in Spectroscopy. Determination of molecular point groups for simple systems and their Physical properties.

Section II: Nonlinear Dynamics

1. Dynamical System, constants of motion, phase space, fixed points. Nonlinear dynamical systems in Physics, biology, engineering, etc. Dynamical equations and Stability for linear systems. Flow defined by nonlinear systems of ODEs, linearization and stable manifold theorem. Hartman-Grobman theorem. Stability and Lyapunov functions. Bifurcation theory: saddle-node, pitchfork, and transcritical bifurcations. Normal forms. Applications in: laser model, magnetism, population dynamics. 2D linear flows: saddle point, nodes, foci, centers and nonhyperbolic critical points. 2D nonlinear flows: stability analysis, Conservative systems: Pendulum equation and double well potential. Applications in: Josephson junction.
2. Limit cycle oscillations and Chaos: Concept of limit cycle, Hopf bifurcation, Poincare- Bendixon theorem; role of nonlinearity: From harmonic oscillator to Van der Pol oscillator, Chaos, Lorenz equation and Rossler

equation. Applications in: Chaos in electronic oscillators, chaos in Laser system.

3. Discrete time nonlinear systems: logistic map, sine circle map, linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; universality and the Figenbaum numbers; bifurcation and chaos, intermittency, crises; Applications in: population dynamics, discrete phase-locked loop system, power electronics.

4. Dispersion, Dissipation and nonlinearity, Korteweg–de Vries (KdV) equation, solitory waves and soliton interaction, Application of KdV equation.

5. Pattern formation: Turing pattern. Reaction Diffusion theory. Diffusion driven instability.

Books Recommended:

1. 'Group Theory and its Applications to Physical Problems - M. Hammermesh. Addison-Wesley

2. Group Theory and Quantum Mechanics M. Tinkham, McGraw-Hill.

3.Group Theory A. W. Joshi. Wiley Eastern Ltd

4. Chemical Application to Group Theory, F. A. Cotton. Wiley Eastern Limited.

5. Group Theory in Chemistry, D. M. Bishop, Dover Publications

6. Steven Strogatz. "Nonlinear Dynamics and Chaos: With Applications to Physics,

Biology, Chemistry, and Engineering", Levant Publishers, 1994.

7. Edward Ott, Chaos in Dynamical Systems, Cambridge University Press.

8. Dominic Jordan, Peter Smith, "Nonlinear Ordinary Differential Equations: An

Introduction for Scientists and Engineers" (Oxford Texts in Applied and Engineering

Mathematics)

9. R. C. Hilborn, Chaos and Nonlinear Dynamics, Oxford University Press

COURSE OUTCOME

Symmetry is a core area in various branches of science. The detailed discussion about the application of symmetry help students to understand the behavior of various natural phenomena in different fields in physics.

At the end of the course the students will be able to

CO1: Explain the impact of nonlinearity on the natural phenomena.

CO2: Solve paradigmatic problems in physics that can not be solved using the

conventional linear approach.

CO3: Apply the knowledge to understand the problems from biology, chemistry, and engineering.

CO4: Apply the skills to pursue research in the multidisciplinary fields.

Course code: PG1PHYS 1015 (Advanced General Practical)

List of Experiments

Group A:

1. Determination of temporal coherency of a coherent (laser) light and compare it with incoherent light (sodium)
2. Study of magneto-optic effect (Faraday effect)
3. Study of electro-optic effect (Pockels effect)
4. Measurement of bending loss in a multi-mode optical Fiber.
5. Study of characterization of antenna
6. Design of active filters (a) band-pass filter, (b) all pass filters
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Studies on LED modulation characteristics
9. Arc emission and absorption measurements using CCD based Constant Deviation Spectrometer.
10. Band gap evaluation of a semiconductor by studying temperature variation of resistance.

Group B:

1. Study of ultrasonic diffraction using a laser
2. Study of gamma ray spectrum of radioactive nuclides with NaI (Tl) scintillators & SCA
3. Study of beta-ray absorption & determination of mass absorption co-efficient of the given absorber material.
4. Study of gamma-ray absorption & determination of gamma ray energy
5. Determination of particle size of an unknown powder specimen using Scherrer equation from supplied XRD pattern
6. Phase identification of an unknown sample from its X-ray diffraction pattern
7. Identification of liquid, solid or powder samples using Laser Raman Spectrometer.
8. Study of NMR.
9. Intensity dependent nonlinear susceptibility of nonlinear liquid by Z-Scan technique.

10. Determination of grove spacing of a CD by diffraction method and hence determination of wavelength of unknown source.

COURSE OUTCOME

This course contains some state of the art experiments for introducing students to the modern research laboratories. The students are highly benefited from these experiments some of which are even used by our research scholars. This course contains experiments from different areas in Physics which enables students to have an overall exposure to the advanced level of equipment and technologies.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

Semester –II

Course Type	Code & Level	Name of the Course	Credit	L – T - P	Marks	Marks Dist. Th. – Pr. - IA
Research Thesis/ Project	**PG1 PHYS 2031**	Research Thesis/ Project	20	0- 0- 20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (50 Marks, 4 credits) & Viva-voce (50 Marks, 4 Credits)-100 Marks, 8 Credits

OPTION- II: Only Course- work in 1st & 2nd Semesters

Semester -I

Course code: PG1PHYS1011 (Advanced Mathematical Physics & Advanced Quantum Mechanics)

COURSE OBJECTIVE: *The aim of this course is to introduce the students with the advanced mathematical techniques and a few topics of quantum mechanics.*

50 Hours

Section I: Advanced Mathematical Physics

1. Integral Transforms: Fourier, Laplace, Hankel and Mellin transforms, Inverse transforms, Convolution theorem, Solution of ordinary and partial differential equations by transform methods.

Discrete Transforms: Z transform, Inverse Z transform, Shifting property, Solution of difference equations using Z transform method, Convolution theorem.

2. Green's functions for ordinary and partial differential equations of mathematical physics, Integral equations, Fredholm and Volterra equations of the first and second kinds, Solution of integral equations by using Integral transforms, Generating functions, Neumann series, Separable (degenerate) kernels methods, Hilbert – Schmidt theory.

3. Tensor analysis, Coordinate transformations, Scalars, Covariant and Contravariant tensors, Addition, subtraction, outer product, inner product and contraction, Symmetric and antisymmetric tensors, Quotient law, Metric tensor, Conjugate tensor, Length and angle between vectors, Associated tensors, Raising and lowering of indices.

Tensor calculus, Differentiation of a tensor, The Christoffel symbols and their transformation laws, Covariant derivative of tensors.

Section II: Advanced Quantum Mechanics

Time dependent perturbation theory, Harmonic perturbation, Fermi's golden rule, Adiabatic and sudden approximations.

1. Relativistic Quantum Mechanics: The Klein Gordon (KG) equation, Covariant notations, Free particle energy, Negative energy and negative probability density, KG equation in an electromagnetic field.

The Dirac equation, Probability density and current, Properties of the Dirac matrices, Dirac γ matrices, the continuity equation, Free particle at rest, Plane wave solutions, Interpretation of –ve energy solutions The Dirac particle in an external electromagnetic field, The non-relativistic limit of the Dirac equation and the magnetic moment of the electron, Covariant form of the Dirac equation, Lorentz covariance of the Dirac equation.

2. Quantum Dynamics: The equations of motion, the Schrödinger picture, the Heisenberg picture, the Interaction picture.

3. Identical Particles: The identity of particles, Spins and statistics, Exchange degeneracy, Symmetrization postulate, Wave function of a two-particle system, Wave function of many-particle system, Example.

4. Scattering theory: Scattering of a particle by a fixed centre of force, Scattering amplitude, Differential and

total cross sections, Partial wave analysis for elastic scattering, Optical theorem, Scattering by a hard sphere, Scattering from a potential well, The Born approximation, The first Born approximation, Validity of the first Born approximation, Scattering from Yukawa and Coulomb potential.

5. Bell's theorem and Quantum Entanglement.

Books Recommended:

1George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.

2. J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.

3. P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists

4. Quantum Mechanics by Claude Cohen-Tannnoudji, Bernard Diu, Franck Laloë (Vol I and II).

5. Quantum Mechanics Concepts and Applications, Second Edition by Nouredine Zettili.

6. Quantum Mechanics by V.K. Thankappan.

7. Problems and Solutions on Quantum Mechanics, Edited by Yung-Kuo Lim.

8. Relativistic Quantum Mechanics- Walter Greiner, Springer-Verlag

9. Advanced Quantum Mechanics – J.J. Sakurai, Addison-Wesley Publishing Company, Inc.

10. Relativistic Quantum Mechanics – J.D. Bjorken and S.D. Drell, McGraw-Hill, New York.

COURSE OUTCOME

The students will learn the fundamentals and the use of Fourier and Laplace transforms, their inverse transforms and convolution theorem. The student is expected to become familiar with the method of Green's function to solve linear differential equations with inhomogeneous term. They will get knowledge of how to find solutions of integral equations by using different methods. They will also get knowledge of the tensor analysis and tensor calculus for formulating and solving problems in areas of physics. The students will learn about the relativistic quantum mechanics, the branch that includes the special theory of relativity in quantum mechanics and different pictures of quantum dynamics. They will acquire knowledge of treating identical particles and scattering phenomenon

Course code: PG1PHYS1012 (Advanced Electrodynamics and Advanced Computational Physics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different theories and applications of advanced electrodynamics and train the students to perform advanced computational programming using different languages.*

50 Hours

Section I: Advanced Electrodynamics

Lineard-Wiechart potentials, Fields of a uniformly moving charge, Fields of an accelerated charge: Fields, radiation (power) and angular distribution from a charge at low velocity (non-relativistic), radiation (power) from a charge at linear motion and circular motion or orbit, frequency spectrum from linearly accelerated charge, Bremsstrahlung-Cerenkov radiation. Radiation from a localised oscillating charges, near and far zone field, multipole expansion, electric dipole radiation, magnetic dipole radiation, quadruple radiation, classical theory of electron: radiation reaction from energy conversation: Abraham-Lorentz theory, self-force. Lorentz transformations of observables: Transformations of electric and magnetic fields, Covariance and contravariance, Examples of 4-vectors: x, del, p, J, A, u.

Wave Guides: Wave guides and resonant cavities, Basic concepts of waveguides, TE and TM modes, Rectangular waveguide, circular waveguide, resonant cavities, rectangular cavity resonator-TE, TM modes. Power loss in a cavity-Q of a cavity.

Section II: Advanced Computational Physics

Introduction to Python programming: The Python Interpreter, Python console, Jupyter and python IDEs; Setting up and using python on GNU/Linux, Windows and Android operating systems; Simple Input and Output; Variables; Mathematical Operators; list, string, tuple, set, dictionary; Control flow and decision control: logical loop structure; Functions and lambdas; Object and class; Files: reading and writing. Python namespaces, installation, design and import of modules in python.

Scientific Computing in Python: Introduction to the Numerical Python (numpy), Scientific Python (scipy), and matplotlib modules. Numpy arrays; Initialization and basic operations; resizing; slicing of arrays; array as a matrix; 2D plotting with matplotlib; plot with external data. Curve-fitting with scipy, linear algebra with numpy. Solution to linear systems of equations (electrical circuit example), eigenvalue problem (anharmonic oscillator example).

Ordinary Differential Equations: initial Value problem and boundary value problem. Simple Euler and Runge-Kutta

methods. Application in physics problems: damped harmonic oscillator, forcing and resonance; self sustained oscillation (van der Pol oscillator, Lorenz oscillator); visualization in phase space. Partial Differential Equations: Laplace and Wave equations. Schrödinger equation and solutions to the eigenvalue problem for simple systems.

Books Recommended:

1. Marion- Classical Electrodynamics
2. Jackson- Classical Electrodynamics
3. Panofsky & Phillips- Classical Electrodynamics
4. Chen- Plasma Physics
5. Griffith-Electrodynamics
6. Numerical Python: Scientific Computing and Data Science Applications with Numpy, SciPy and Matplotlib, R. Johansson, 2019, Apress.
7. Computational Physics: Problem Solving with Python, 3rd Edition, Rubin H. Landau, Manuel J Páez, Cristian C. Bordeianu, 2015, Wiley.
8. Scientific Computing in Python, Abhijit Kar Gupta, Techno world, 2019.
9. Let Us Python, 2nd Edition, Y. Kanetkar, A. Kanetkar, 2020, BPB Publications.
10. Computational Physics, N.J. Giordano, 1997, Prentice-Hall.
11. Python and matplotlib essentials for scientists and engineers, Matt A. Wood, 2015, Morgan and Claypool Publishers.
12. Introducing Python: Modern Computing in Simple Packages, B. Lubanovic, 2015, O'Reilly Media, Inc.

COURSE OUTCOME

On completion of the course, the student should be able to:

- Learn the fundamental of the Electrodynamics which deals with the LW potentials, radiation emitted by a charged particle in linear as well as in circular path and its applications.
- learn Bremmstrahlung-Cerenkov Radiation
- Translate a theoretical or algorithmic model into code that enables computation, logically subdivide a computational model into a set of manageable computational tasks, and organize their code accordingly, choose among computational algorithms and computational tools to produce a solution, debug, test, and validate computational models, and extract physical insight from a computation.
- Use the Python programming language to numerically solve physics problems, focussing on the use of Python's numeric modules SciPy (Scientific Python), Numpy (Numerical Python), and graphics module Matplotlib (MATLAB-like Plotting Library).

- Apply Monte Carlo simulations, curve-fitting and interpolation of datasets, numerically solve systems of nonlinear equations, ordinary differential equations, multiple integrals, perform computational linear algebra, solve optimization problems, perform signal analysis using Fast Fourier Transforms etc
- Formulate and computationally solve any tractable problem in physics,

Course code: PG1PHYS1013 (Atomic Physics and Particle Physics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different advanced theories and phenomenona of atomic physics and particle physics.*

50 Hours

Section I: Atomic Physics

1. General discussion on one electron atoms, hydrogen and hydrogen-like systems, Degeneracy and spectra, Quantum defect, Fine Structure - Relativistic effects, Spin Orbit interaction, Lamb shift,
2. Spectra of divalent atoms: Approximations, Singlet and triplet states.
3. Many electron atoms. Hamiltonian, Approximations. L-S and j-j coupling, complex spectra, equivalent and non-equivalent electrons Hunds Rule and its applications
4. Effect of magnetic field on the above spectra, Zeeman and Paschen-Back effects.
5. Hyperfine structure in spectra of monovalent atoms, origin of X-rays spectra,
6. Laser in Spectroscopy:

(i) Absorption spectroscopy, (ii) excitation spectroscopy, (iii) ionization spectroscopy, (iv) saturation spectroscopy, (iv) photo acoustic spectroscopy, (v) opto-galvanic spectroscopy, Doppler-free spectroscopy, Tera Hertz spectroscopy with innovative applications.

Section II: Particle Physics

Radioactive decay: Basic ideas of alpha, beta and gamma decays. Gamma emission & kinematics, multipolarity and selection rules.

Elementary particles and their interactions:

A brief historical development; Classification of elementary particles; antiparticles and crossing symmetry; strange and resonance particles; fundamental interactions: typical strengths, range, time-scales; Feynman diagrams; Symmetries and conservation laws; Charge conjugation, Parity and Time reversal; G-parity; CPT theorem; CP violation in K^0 decay.

Weak interactions

Leptonic, semi-leptonic and non-leptonic interactions; beta spectrum and energetics; Fermi's theory of beta decay; Coulomb correction and Fermi-Kurie plot; allowed and forbidden transitions, selection rules; Non-conservation of parity in beta decay: τ-θ paradox, Wu's experiment; detection of the neutrino and its helicity; Goldhaber's experiment.

Strong interactions

SU(2) and SU(3) symmetry (qualitative); Gell-Mann–Nishijima relation; Symmetry classification of elementary particles (eightfold way): baryon and meson octet and decuplet; discovery of Ω^- baryon; Quark model and SU(3) flavor symmetry; charm, beauty and truth, idea of color; quark-confinement and asymptotic freedom.

Recommended books

1. Physics of Atoms and Molecules --- B. H. Bransden and C. J. Joachin (2nd Ed), Pearson, 2003
2. Basic Atomic and Molecular Spectroscopy ---- J. M. Hollas, RSC Publishing, 2002
3. Spectra of Atoms and Molecules, Peter Bernath, 2nd Ed, Oxford University Press, 2005
4. Introduction to Atomic Spectroscopy: H. E. White, Dover Publication, 1934
5. Atomic and Laser Spectroscopy: Allan Corney, Clarendon Press, Oxford.
6. Laser in Chemistry- D L Andrew
7. Modern Particle Physics-Mark Thompson, (Cambridge University Press).
8. Introduction to High Energy Physics-D H Perkins, (Cambridge University Press).
9. Introduction to elementary particles-D J Griffiths, (Wiley, 2008).
10. Quarks and Leptons: An introductory course in modern particle physics - F. Halzen and A.D. Martin (John Wiley & Sons)

COURSE OUTCOME

This course gives a thorough account of the processes occurring at the atomic level. Both experimental and theoretical approaches are discussed at length. The students will have a detailed understandings of the basic processes (at the electronic level) occurring inside an atom, when it is isolated as well as when it is under a force field. Various spectroscopic techniques in the syllabus will help them in a long way to enter into research arena as well as in industrial sectors involving R&D in various fields. In addition to the completion of this course, students should be able to:

- Understand the fundamental constituents of matter and their interactions.
- Explain the development of particle physics from hadrons to the Standard Model.
- Apply symmetry principles and conservation laws to particle interactions.

- Explain symmetry principles in particle physics.

The basic knowledge about elementary particles and interactions will be useful for the students for future theoretical or experimental research in high energy physics.

Course code: PG1PHYS1014 (Group Theory and Non-linear Dynamics)

COURSE OBJECTIVE: *The aim of this course is to equip the students with the different methods and applications of group theory and non-linear dynamics.*

40 Hours

Section I: Group Theory

1. Abstract group theory:

Definition. Group axioms. Finite and infinite groups, Nature of a group, Rearrangement theorem. Group multiplication table. Subgroups and Cosets. Lagrange's theorem. Order of an element. Conjugate elements and classes. Cyclic and other distinct groups. Permutation groups. Invariant subgroups, factor groups. Generators. Isomorphism and homomorphism. Illustrations with point symmetry groups

2.**Representation theory**.

Definition, Faithful and unfaithful representations. Reducible and irreducible representations. Schur's lemmas, Great orthogonality theorem and its geometrical interpretation. Character. First and second orthogonality theorems of characters and its geometrical interpretation. Regular representation, celebrated theorem and its implication. Construction of character tables of simple groups.

3.**Continuous group**

Infinite groups. Discrete and continuous groups. Lie groups. Axial rotation group SO(2). Rotation group SO(3). Special Unitary groups SU(2) and SU(3) and their application in Physics.

4.**Application in Physics**

Group of Schroedinger equation and degeneracy. Application in Spectroscopy. Determination of molecular point groups for simple systems.

Section II: Nonlinear Dynamics

1. Dynamical System, constants of motion, phase space, fixed points. Nonlinear dynamical systems in Physics, biology, engineering, etc. Dynamical equations and Stability for linear systems. Flow defined by nonlinear systems of ODEs, linearization and stable manifold theorem. Hartman-Grobman theorem. Stability and

Lyapunov functions. Bifurcation theory: saddle-node, pitchfork, and transcritical bifurcations. Normal forms. Applications in: laser model, magnetism, population dynamics. 2D linear flows: saddle point, nodes, foci, center and nonhyperbolic critical points. 2D nonlinear flows: stability analysis, Conservative systems: Pendulum equation and double well potential. Applications in: Josephson junction.

2. Limit cycle oscillations and Chaos: Concept of limit cycle, Hopf bifurcation, Poincare-Bendixon theorem; role of nonlinearity: From harmonic oscillator to Van der Pol oscillator,Chaos, Lorenz equation and Rossler equation. Applications in: Chaos in electronic oscillators, chaos in Laser system.

3. Discrete time nonlinear systems: logistic map, sine circle map, linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; universality and the Figenbaum numbers; bifurcation and chaos, intermittency, crises; Applications in: population dynamics, discrete phase-locked loop system, power electronics.

4. Dispersion, Dissipation and nonlinearity, Korteweg–de Vries (KdV) equation, solitory waves and soliton interaction, Application of KdV equation.

5. Pattern formation: Turing pattern. Reaction Diffusion theory. Diffusion driven instability.

Books Recommended:

1. 'Group Theory and its Applications to Physical Problems - M. Hammermesh.. Addison-Wesley

2. Group Theory and Quantum Mechanics M. Tinkham, McGraw-Hill.

3.Group Theory A. W. Joshi. Wiley Eastern Ltd

4. Chemical Application to Group Theory'F. A. Cotton. '. Wiley Eastern Limited.

5. Group Theory an Chemistry D. M. Bishop Dover Publications

6. Steven Strogatz. "Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering", Levant Publishers, 1994.

7. Edward Ott, Chaos in Dynamical Systems, Cambridge University Press.

8. Dominic Jordan, Peter Smith, "Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers" (Oxford Texts in Applied and Engineering Mathematics)

9. R. C. Hilborn, Chaos and Nonlinear Dynamics, Oxford University Press

COURSE OUTCOME

Symmetry is a core area in various branches of science. The detailed discussion about the application of symmetry help students to understand the behavior of various natural phenomena in different fields in physics.

At the end of the course the students will be able to

CO1: Explain the impact of nonlinearity on the natural phenomena.

CO2: Solve paradigmatic problems in physics that can not be solved using the conventional linear approach.

CO3: Apply the knowledge to understand the problems from biology, chemistry, and engineering.

CO4: Apply the skills to pursue research in the multidisciplinary fields.

Course code: PG1 PHYS 1015 (Advanced General Practical)

List of Experiments

Group A:

1. Determination of temporal coherency of a coherent (laser) light and compare it with incoherent light (sodium)
2. Study of magneto-optic effect (Faraday effect)
3. Study of electro-optic effect (Pockels effect)
4. Measurement of bending loss in a multi-mode optical Fiber.
5. Study of characterization of antenna
6. Design of active filters (a) band-pass filter, (b) all pass filters
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Studies on LED modulation characteristics
9. Arc emission and absorption measurements using CCD based Constant Deviation Spectrometer.
10. Band gap evaluation of a semiconductor by studying temperature variation of resistance.

Group B:

1. Study of ultrasonic diffraction using a laser
2. Study of gamma ray spectrum of radioactive nuclides with NaI (Tl) scintillators & SCA
3. Study of beta-ray absorption & determination of mass absorption co-efficient of the given absorber material.
4. Study of gamma-ray absorption & determination of gamma ray energy
5. Determination of particle size of an unknown powder specimen using Scherrer equation from supplied XRD pattern

6. Phase identification of an unknown sample from its X-ray diffraction pattern
7. Identification of liquid, solid or powder samples using Laser Raman Spectrometer.
8. Study of NMR.
9. Intensity dependent nonlinear susceptibility of nonlinear liquid by Z-Scan technique.
10. Determination of grove spacing of a CD by diffraction method and hence determination of wavelength of unknown source.

COURSE OUTCOME

This course contains some state of the art experiments for introducing students to the modern research laboratories. The students are highly benefited from these experiments some of which are even used by our research scholars. This course contains experiments from different areas in Physics which enables students to have an overall exposure to the advanced level of equipments and technologies.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

Semester -II

Course code: PG1PHYS2011 (Molecular Physics)

COURSE OBJECTIVE

The aim of this course is to equip the students with the different advanced theories and experiments involving molecular physics and characterization of molecules

50 Hours

1. Born-Oppenheimer approximation and separation of electronic and nuclear motions in molecules. Band structures of molecular spectra.
2. Microwave and far infrared spectroscopy: Energy levels of diatomic molecules under rigid rotator and non-rigid rotator models. Selection rules. Spectral structure. Structure determination. Isotope effect. Rotational spectra of polyatomic linear and symmetric top molecules. Stark effect.
3. Infrared spectra: Energy levels of diatomic molecules under simple harmonic and anharmonic (no deduction necessary for this one) models. Selection rules and spectral structures. Morse potential energy curves. Dissociation energies. Isotope effect. Rotational – vibrational coupling.P and R branches of lines, Band origin, Parallel and perpendicular modes. Symmetry properties of molecular wave functions and absence of spectral lines.

4. Raman spectroscopy. Rotational, Vibrational, Rotational-Vibrational Raman spectra. Stokes and anti stokes Raman lines. Selection Rules. Spectral structures. Nuclear spin and its effect on Raman spectra.
5. Vibrational spectra of poly atomic molecules. Normal modes. Selection rules for Raman and infrared spectra. Complementarity of Raman and infrared spectra, Normal modes of CO_2 molecule. Normal modes of other simple triatomic molecules.
6. Electronic spectra of diatomic molecules
   (a) Vibrational band structure. Progressions and sequences. Isotope shifts. Desl and restables. Molecular constants in the ground and excited electronic states and crude idea of molecular bonding.
   (b) Rotational structure of electronic spectra. P-, Q- and R- branches. Band head formation and shading of bands.
   (c) Intensity distribution in the vibrational structure of electronic spectra and Franck-Condon principle. Hund's coupling. Experimental determination of dissociation energy.
   (d) Hydrogen molecule ion and molecular orbitals. Valence Bond approach in hydrogen molecule. Coulomb and exchange integrals. Electronic structures of simple molecules. Chemical bonding. Hybridizations.

(e) Basic aspects of photo physical processes: radiative and non-radiative transitions; fluorescence and phosphorescence; Kasha's rules. Nuclear Magnetic resonance spectroscopy. Electron spin resonance spectroscopy. Fourier transform spectroscopy. Photo electron spectroscopy. Mossbauer spectroscopy.

(f) Application of group theory to spectroscopy.

7. Nonlinear spectroscopy: Laser Raman spectroscopy.

Books Recommended:

1. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.
2. G. M. Barrow. 'Molecular Spectroscopy' McGraw-Hill.
3. J. Michael Hollas. 'Modern spectroscopy' John-Wiley & sons.
4. C. L. Banwell and E. M. Mc Cash. 'Fundamentals of Molecular Spectroscopy', Tata- McGraw-Hill..
5. G.Aruldhas 'Molecular Spectroscopy'.
6. Physics of Atoms and Molecules --- B. H. Bransden and C. J. Joachin (2^{nd} Ed), Pearson, 2003.
7. F.A.Cotton. 'Chemical application to Group theory'.

COURSE OUTCOME

Molecular Spectroscopy is a very old branch of basic physics. Going through this course/Paper the Students can get knowledge on different internal motions of molecules and their interactions. The can get ideas/concepts on the role of Molecular rotations, vibrations, electronic motions in various types of absorption and emission spectra from molecules and their practical applications. They can get knowledge on Raman Spectroscopy and also their practical implications. The Students can get expertise to analyze the molecular spectrum based on orbital theory as well as valance band theory of molecules. Some ideas on nonlinear spectroscopy and stimulated Raman Spectroscopy (Laser Raman Spectroscopy) will also be given to them.

Course code: PG1PHYS2012 (Discipline Specific Elective I)

COURSE OBJECTIVE: *The objective of the course is to enable the students to learn about different advancements in the fields of Electronics, Astrophysics & Cosmology, Materials Science, Condensed Matter Physics, Nuclear & Particle Physics and LASER physics.*

50 Hours

1. Advanced Electronics-I

1. Microwave Vacuum tube devices: Problems of microwave generation in conventional oscillators. Klystron and Reflex Klystron, Magnetrons, Slow wave structure and Travelling wave tubes.

2. High frequency solid state devices: Tunnel diode, Gunn diode, Impatt, Trapatt.
3. IC Technology: Hybrid and monolithic IC; Semiconductor processing diffusion,
implanation, oxidation, epitaxy, lithography; Si IC technology-MOS and Bipolar; Packaging and testing.
4. Analog Integrated Circuits: Differential amplifier, internal structure of op-amp; continuous time filters, switched capacitance implementation of sample data filters; analog multiplexers, PLL and frequency synthesizer.
5. Digital Integrated Circuits: Logic families – TTL, ECL, MOS, MESFET; design of combinational and sequential circuits – MUX, decoder/ encoder, registers, counters, gate arrays.
6. Memories: Sequential and Random access memories; RAM bipolar and MOS static and dynamic memories; programmable memories PROM, EPROM, EEPROM.
7. Introduction to quantum computing: Quantum logic gates, Quantum circuits.

Books Recommended:

1. R E Collin - Foundations of Microwave engineering.
2. S.Y. Liao – Microwave Devices on circuits.
3. Milman and Grable, Microelectronics. Tata MacGraw Hill.
4. Geiger, Allen and Strader – VLSI – Design Techniques for Analog and Digital
Circuits.
5. Gray and Meyer – Analysis and Design of Analog Integrated Circuits.
6. S Soelof – Applications of Analog Integrated Circuits.

COURSE OUTCOME

At the end of the course, the students will be able to
CO1: Analyze the operating principles, characteristics, and applications of microwave vacuum tube devices and high-frequency solid-state microwave devices.
CO2: Evaluate semiconductor fabrication processes and IC technologies.
CO3: Design and analyze analog integrated circuits and digital integrated circuits,
including logic families, combinational and sequential logic circuits, registers, counters,
gate arrays, and semiconductor memory systems.
CO4: Interpret and apply the principles of quantum computing to construct and analyze
simple quantum logic gates and quantum circuits, and compare them with classical digital
logic systems.

2: Astrophysics & Cosmology-I

A. General Theory Relativity:

1. Review of Mechanics of Continuous Media:

Equation of continuity, 4-D formulation, comoving coordinate system, Energy momentum tensor of continuous media.

2. Space-Time Geometry:

A critical review of space, time and gravity, Euclidean and non-Euclidean space-time, Parallel transport in flat and curved Spaces, affine connection, Covariant derivatives, covariant derivative of vectors, covariant derivative of tensors, metric tensors, Geodesics, Geodesics on spherical surface, Riemann Christoffel tensors, Ricci tensors, Bianchi Identities, Einstein tensors, necessary and sufficient condition for flatness of space-time, Newtonian gravity in metric tensor form.

3. Einstein's Gravity:

Inconsistencies of Newtonian gravitation with Special Theory of Relativity, Need for a curved space-time, Principle of equivalence, Inertial and gravitational mass, Principle of general covariance, heuristic derivation of Einstein's law of gravitation, weak field approximation of Einstein's gravity.

4. Solutions of Einstein's Field Equations and Static Black Holes:

Schwarzschild solution, exterior solution, Birkhoff's theorem, isotropic coordinates, singularity, Schwarzschild radius and event horizon, Schwarzschild interior solution, Schwarzschild solution in other coordinate systems, Circular geodesic of a particle in Schwarzschild space – time, minimum radius, motion of a test particle, trajectories of photons; Geodesic equation in Schwarzschild space-time, Bending of light rays in a gravitation field, gravitational red shift, Precession of perihelion of Mercury, Analogues of Keplar's laws,

B. Advanced Cosmology

1. Introduction:

Large scale structure of the universe, Cosmological scales, Weyl postulates, Cosmological Principles, Static Universe model – Einstein Model, de-Sitter Model, Properties of Einstein and de-Sitter universes, cosmological constant and its significance, Discussion on Newtonian cosmology, red shift.

2. Non static model of the universe:

Friedmann model of the universe, Field equations, Energy-Momentum tensors (perfect fluid) of the universe, Friedmann-Robertson-Walker metric (derivation is not required), Cosmological parameters, Static Universe and Expanding universe, Hubble' law, scale factor, present day scale factor, Models of F-R-W universes (k=0,+1,-1),

density and volume of the universe, Open and Closed universes, Cosmological red shift, Hubble time and age of the universe, cosmological models with Λ-term, Particle Horizon and Event Horizon, Olber's Paradox.

3. Qualitative discussions on: Big Bang, very early universe, vacuum energy, false vacuum energy, Grand Unified Theory (GUT

4. Observational Cosmology:

Red shift – magnitude relation, Hubble diagram using type I_a supernova, number counts of extra galactic objects, last scattering surface, Cosmic Microwave Background Radiation.

5. Dark Energy and Dark matter:

Elementary analysis on Dark Energy and Dark Matter, evidences in support of Dark Energy and Dark Matter. Origin and nature of Dark Energy, galaxy rotation curves.

Books Recommended

Part A:

An Introduction to Relativity, J. V. Narlikar (Cambridge University Poress, 2010).

S. Banerji and A. Banerjee – The Special Theory of Relativity (Prentice Hall of India, 2002)

P. G. Bergmann- Introduction to Theory of Relativity (Pren tice-Hall, 1969).

J. V. Narlikar- General Relativity and Cosmology (MacMillion, 1978).

S. Banerji and A. Banerjee, General Relativity and Cosmology – (Elsevier, 2007)

A. K. Raychaudhuri, S.Banerji and A. Banerjee General Relativity, Astrophysics and Cosmology – (Springer-Verla, 1992)

J. V. Narlikar –Introduction to Cosmology (Cambridge Univ, Press, 2003).

S. Weinberg- Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity (Wiley, 1972).

V. B. Bhatia - Textbook of astronomy an astrophysics with elements of cosmology, Narosa publishing house, (2001).

E. W. Kolb and M. S. Turner - The Early Universe –(Addison-Wesley Reading, 1990)

Part B:

1.A short course in General Relativity, J. Foster and J. D. Nightingle (Longman Inc., NY, 1979)

2. Theoretical Astrophysics (Vols. I, II, III) , T. Padmanavan

3. General Relativity, Astrophysics and Cosmology, A. K. Raychaudhuri, S. Banerji and A. Banerjee (Springer-Verla, 1992)

4. General Relativity and Cosmology, S. Banerji and A. Banerjee (Elsevier, 2007)

5. An Introduction to Relativity, J. V. Narlikar (Cambridge University Poress, 2010)

6. General Relativity and Cosmology, J. V. Narlikar (MacMillion, 1978)
7. Theory of Relativity - S. Weinberg (Wiley, 1972).
8. Introduction to Theory of Relativity, P. G. Bergmann (Prentice-Hall, 1969)
9. Astrophysics for Physicists, Arnab Rai Choudhuri (Cambridge University Press 2012)
10. Gravitation, C. W. Misner, K. S. Thorne and J. A. Wheeler (Princeton University Press, 2017)

LEARNING OUTCOMES:

Astrophysics & Cosmology-I is a Discipline-centric Elective (DE) course in Semester-IV. The students who opted this course have to study advanced topics on General Relativity and its application on Astrophysical tests and Black Hole physics. This course is designed to ensure the global competitiveness for higher study. The students who has opted this course also have to study advanced topics on Cosmology and its application to understand the physics of large scale universe specially, expanding universe, standard model of universe, early history of the universe as well as observational aspects of the cosmology. The students can develop their concept and basics understanding from the course and make their mind set to fit with the global competitiveness such that one can go for higher doctoral study.

3. Materials Science-I

Applied crystallography in materials science

Noncrystalline and semicrystalline states, Lattice. Crystal systems, unit cells. Indices of lattice directions and planes. Coordinates of position in the unit cell, Zones and zone axes .Crystal geometry. Symmetry classes and point groups, space groups. Glide planes and screw axes, space group notations, Equivalent points. Systematic absences, Determination of crystal symmetry from systematic absences.

X-ray scattering:

Continuous spectrum and characteristic spectrum, Duane-Hunt law. X-ray energy level schemes, diagram and non-diagram lines, Absorption of X-rays and theory of filters.

General description of scattering process, coherent and incoherent scattering, total scattering from a spherically symmetric electron cloud, Atomic scattering factor. Coherent and incoherent scattering from hydrogen atom, scattering from many electron atom (outline). Perfect crystal theory: Intensity form a small single crystal, integrated intensity from a small perfect crystal (no deduction), integrated reflection from mosaic and powder crystal.

Thermal properties of metals & alloys

Temperature effects on the intensities of Bragg reflections. Influence of temperature on diffraction of X-rays: Normal coordinates of lattice vibration and X-ray scattering from a vibrating lattice and origin of thermal diffuse spots. First order TDS. Debye-Waller factor' Debye's method of calculating isotropic temperature factor for a cubic crystal.

DTA, TGA, DSC (Outline only).

Microstructure characterization by direct & indirect methods

Diffraction techniques: interpretation of x-ray powder diffraction patterns, Identification & quantitative estimation of unknown samples by X-ray powder diffraction technique. Theory and method of particle size analysis.

Scanning electron microscopy (SEM), Transmission electron microscopy (TEM). Electron and neutron diffraction.

Computational methods in Materials Physics

Density Functional Theory: Basics of DFT, Comparison with conventional wave function approach, Hohenberg-Kohn Theorem; Kohn-Sham Equation; Practical DFT in a many body calculation.

Books Recommended:

1. Materials science and Engineering by V. Raghavan, Prentice-Hall Pvt. Ltd.

2. X-ray diffraction by B. E. Warren, Addison-Wesley Publishing Co.

3. Elements of X-ray diffraction by B. D. Cullity, Addison-Wesley Publishing Co.

4. Engineering Materials by Kenneth G. Budinski, Prentice-Hall of India Pvt. Ltd.

Course Outcome

(i) Students will be acquainted with the detailed crystal structures of various crystalline materials like metals, alloys, compounds.

(ii) the knowledge of crystallography will lead the students to identify the crystal structures, help to synthesize materials.

4. Condensed Matter Physics-I

1. **Many body techniques**: Second quantization, Creation and annihilation operators for bosons and fermions, The general form for second quantization operators, Change of basis in second quantization, Quantum field operators and their Fourier transforms, Operators for kinetic energy, spin, density, the Coulomb interaction in second quantization. The nearly free electron and tight-binding models in second quantization. Hartree-Fock Theory, the jellium model for free electrons, Coulomb repulsion and electron-phonon interaction term in the jellium model, Hartree Fock equations and the nearly free electron jellium model. Introduction to Green's functions.

2. **Thermal properties:** Harmonic approximation, Force constants, Lattice dynamics, Dynamical matrix, Dispersion relation – a 1D lattice with identical atoms and a 1D lattice with atoms of different masses in alternate sites, Acoustic branch, Optical branch, Brillouin Zone, Branches in 3D: three acoustic branches (one longitudinal, two transverse) and 3(p-1) optical branches for a primitive cell containing p atoms (derivation), polarization.

Phonons & quantization of lattice vibrational energy, Diagonalization of the quantum Hamiltonian for a vibrating

lattice, Energy levels, Density of states (DOS), Specific heat, Einstein and Debye models, Comparison with experimental results.

3. **Phase transitions**: Landau theory of phase transitions: Spontaneous Symmetry Breaking in Landau Theory. Critical phenomena and critical indices.

4. **Superconductivity:** Introduction to superconductivity and the Meissner effect, Ginzburg-Landau theory for superconductors, Cooper instability and the BCS ground state, Bogoliubov solution of the BCS model. The Josephson effects in Ginzburg-Landau theory, dynamics of Josephson junctions, The Bogoliubov-de Gennes Hamiltonian, Andreev reflection

5. Lower Dimensional Systems: Properties of nanoparticles; quantum wells, wires, quantum confinement and dots; shape, size and dimensionality effects; Over view of carbon nanotubes and grapheme. Introduction to one dimensional quantum spin chains.

Books recommended:

1. Condensed Matter Physics, Michael P. Marder Wiley, New York.
2. Condensed Matter in a Nutshell, Gerald D. Mahan, Princeton University Press.
3. Solid State Physics Supppleent-2(Paramagnetic Resonance in Solids): William Low

COURSE OUTCOME

This course continues from the previous course in solid state physics and provides a thorough introduction to interacting many body systems, targeting aspirant researchers in the field. Approaches include applications of classical and quantum physics, statistical physics and electromagnetism towards understanding the emergence of spontaneous order in strongly interacting systems, particularly the phenomenon of superconductivity. Additionally, the study of thermal properties from the classical and quantum theory of the vibrating lattice is included.

A concise but a very important part of the course is the effect of reducing the size to nano-order in different dimensions. At the end of the Course, the students will be able to begin advanced research projects in this area. Thus, this course served as a gateway towards research in Condensed Matter Physics and Materials Science.

5: Nuclear & Particle Physics-I

1. **Experimental Techniques & Nuclear Electronics**

Choice of a detector, HPGe detector. Sensitivity, response, resolution, efficiency, peak-to-total ratio, pulse height spectra. Compton suppression, composite and tracking detectors, Multi-detector arrays.

Electronics & DAQ: Preamps, shaping amplifiers, discriminators (SCA/MCA/CFD), TAC, coincidence logic circuits, flash ADCs, digital signal processing.

Spectroscopy: Energy, timing, position sensitivity; measurement of level spin, parity, lifetime (delayed coincidence, DSAM), and gamma linear polarization.

2. **Exotic Nuclear Physics & Superheavy Elements**

Drip Lines & Halos: Stability limits; 1- & 2-neutron halos (11Li, 11Be, 6He), Borromean systems, neutron skin, soft dipole (pygmy) resonances.

Shell Evolution & Shapes: Magic number breakdown/emergence (N=16, 32, 34), Island of Inversion. Shape coexistence, super-deformation, magnetic rotation, chiral symmetry breaking.

Superheavy Elements (SHE): Synthesis (cold/hot fusion, 48Ca reactions), quasi-fission, Island of Stability, alpha decay chains, spontaneous fission barriers.

3. **Nucleosynthesis & Nuclear Astrophysics**

Stellar Energy: Abundances, Coulomb penetration, quantum tunneling, reaction rates (resonant/non-resonant), electron screening.

Burning Cycles: pp-chain branches, CNO cycle, triple-alpha process, 8Be bottleneck, electron degeneracy, Helium flash.

Element Formation: C/O & explosive burning, s-, r-, and p-processes. Solar neutrino problem; primordial light element (Li, Be, B) origin via spallation.

4. **Health Physics & Radiation Dosimetry**

Quantities & Biology: Activity, Exposure, Dose, KERMA, dE/dx, RBE, Equivalent/Effective dose (HT, E). Direct/indirect DNA damage, deterministic vs. stochastic effects.

Kinetics & Safety: Biological (Tb), physical (Tp), effective (Te) half-lives; internal/committed dose models.

Protection: ICRP principles (ALARA, dose limits). Attenuation (HVL, TVL, buildup), charged particle shielding. Monitoring: pocket dosimeters, TLDs, OSLs, survey meters.

5. **Physics of Medical Imaging**

1D & 2D Radiography. Computed Tomography (CT), Single-Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET). Compton camera. Magnetic Resource Imaging (MRI). Radiotherapy.

Books Recommended

1. Glenn F. Knoll et. al – Radiation Detection and Measurement (4ed, An Indian Adaptation, John

Wiley & Sons)
2. William R. Leo – Techniques for Nuclear and Particle Physics Experiments: A How-to Approach (Springer)
3. Carlos A. Bertulani, Mahir S. Hussein, & Gerhard Muenzenberg – Physics of Radioactive Beams (Nova Science Publishers)
4. Yashitaka Suzuki, Y. Akaishi, & K. Ikeda – Physics of Exotic Nuclei (World Scientific)
5. Christian Iliadis – Nuclear Physics of Stars (Wiley-VCH)
6. Claus E. Rolfs & William S. Rodney – Cauldrons in the Cosmos: Nuclear Astrophysics (University of Chicago Press)
7. Herman Cember & Thomas E. Johnson – Introduction to Health Physics (McGraw-Hill)
8. James E. Turner – Atoms, Radiation, and Radiation Protection (Wiley-VCH)
9. Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt Jr., & John M. Boone – The Essential Physics of Medical Imaging (Lippincott Williams & Wilkins)
10. Faiz M. Khan & John P. Gibbons – Khan's The Physics of Radiation Therapy (LWW)

COURSE OUTCOME

1. Detection & Instrumentation: We can learn the operational principles of radiation detectors, nuclear electronics, pulse processing systems, and spectroscopic measurement techniques.
2. Exotic & Superheavy Physics: We can learn the physics of exotic nuclei, halo structures, shell evolution, and synthesis mechanisms of superheavy elements.
3. Astrophysics & Nucleosynthesis: We can learn how stellar reaction rates, burning cycles, and s-, r-, and p-processes drive element formation in the universe.
4. Dosimetry & Protection: We can learn to calculate radiation doses, evaluate biological effects, and design effective radiation shielding standards.
5. Medical Physics: We can learn the fundamental physical principles and instrumentation underlying diagnostic imaging (CT, PET, SPECT, MRI) and radiotherapy.

6: Laser Physics-I

1. Basic Laser System: Quantum theory for evaluation of the transition rates and Einstein A and B coefficients, allowed and forbidden levels-metastable state; population inversion; rate equations for three level and four level lasers, threshold of power calculation, Basic concept of construction of laser system, various pumping system (incoherent and coherent), pumping cavities for solid state laser system, characteristics of host materials and doped

ions.

2. Optical beam propagation: Paraxial ray analysis, propagation and properties of Gaussian beam, Gaussian beam in lens like medium, ABCD law, M^2 parameter.

3. Resonators: Stability of resonators, 'g' parameters, various types of stable resonators, evaluation of beam waist of such combination, unstable resonator and their applications, Ring Resonator.

4. Q-switching: Giant pulse theory, different active and passive Q-switching techniques: mechanical Q-switching, electrooptic Q-switching, Pockels and Kerr Q-switching, acousto-optic Q-switching, dye Q-switching.

5. Different laser systems:

(i) CO_2 laser; (ii) Nd:YAG laser, (iii) Tunable solid-state laser: Ti:sapphire laser, (iv) HF laser, (v) Excimer laser; (vi) Fibre laser**,** (vii) Free electron laser (viii) semiconductor lasers.

6. Laser instrumentation:

Principle of measurement with laser beam, distance measurement, rotation, fluid velocity measurement, surface velocity measurement using speckle patterns, measurements of rate and rotation using laser gyroscope, Advantages of remote monitoring of the atmosphere by laser, principles of remote monitoring, different lidar systems: single beam, dual beam.

7. Material processing:

Laser in drilling, cutting, welding, marking and annealing.

8. Laser Safety:

Various hazards due to laser radiation-eye, skin, chemical etc., high voltage hazards, safety measures and standard.

Books Recommended:

1. Principles of Lasers- O Svelto
2. Solid State Laser Engineering- W Koechner
3. Quantum Electronics- A Yariv
4. Introduction to Optical Electronics- K A Jones
5. Industrial Application of Lasers – J F Ready

COURSE OUTCOME

On successful completion of the course, the students:

1. Will be able to describe requirements for a system to act as a laser and how lasers work.

2. Will have good understanding on design aspect of different kinds of resonators for various types of lasers and thus will be able to differentiate the various types of lasers and their means of excitation.

3. Will have the knowledge of getting high energy as well as high peak power from suitable lasers.

4. Will be able to identify hazard for eye and skin when irradiated different laser radiations and how such lasers are categorized from Class I to Class IV based on international safety standards.

5. Will have the knowledge of using laser beams to measure distance, fluid velocity, remote monitoring etc apart from being familiar with different lidar systems.

6. Will gain knowledge on an important industrial application of lasers, namely, laser material processing.

Course code: PG1PHYS2013 (Discipline Specific Elective II)

COURSE OBJECTIVE

The objective of the course is to enable the students to learn about different advancements in the fields of Electronics, Astrophysics & Cosmology, Materials Science, Condensed Matter Physics, Nuclear & Particle Physics and LASER physics.

50 Hours

1: Advanced Electronics-II

1. Analysis of networks and systems: Sample data system. Z- transform, Fourier and Laplace transforms.

2. Microwave Transmission lines and Waveguides: Transmission lines, Standing wave ratio, Quarter wave transformer, Smith Chart, Stub matching. Wave guides coaxial, rectangular and cylindrical; Waveguide attenuation, Resonators.

3. Antenna theory: Antennas-dipole, Antenna arrays, reflectors, steering strip, microstrip and coplanar structure.

4. Elements of Information Theory: Information, average information, information rate, Effect of coding on average information per bit; Shannon's theorem; Channel capacity, an optimum modulation system.

5. TV Systems: Color TV standards – NTSC, PAL, SECAM; Transmission format of intensity and color signal; Transmitter and receiver systems of broadcast TV; Advanced TV; Cable TV.

6. RADAR System: Basic pulsed radar system – modulators, duplexer indicators, radar antenna CW radar; MTI radar FM radar; chirped pulse radar.

7. Satellite Communication: Orbits, Station keeping; Satellite attitude; Path loss calculation; Link calculation; Multiple access techniques; Transponders; Effects of nonlinearity of transponders.

8. Specialized Communication Systems: Mobile Communication – Concepts of cell and frequency reuse description of cellular communication standards; Pagers. Computer communication -Types of networks; Circuit message and packet switched networks; Features of network, design and examples of ARPANET, LAN, ISDN, Medium access techniques – TDMA, FDMA, ALOHA, Slotted ALOHA, CSMA/CD; Basics of protocol.

Books Recommended

1. R E Collin - Foundations of Microwave engineering.

2. S.Y. Liao – Microwave Devices on circuits.
3. A M Dhake – Television and Video Engineering.
4. Gulati – Monochrome and Color TV.
5. Kennedy and Davis – Electronic Communication Systems.
6. Taub and Schilling – Principle of Communication Systems.

COURSE OUTCOME

At the end of the course, the students will be able to

CO1: Analyze communication networks and transmission systems using Fourier, Laplace, and Z-transforms, and

CO2: Evaluate the performance of microwave transmission lines, waveguides, impedance-matching techniques, and resonators.

CO3: Evaluate the design principles and performance characteristics of antennas, information-theoretic measures, coding techniques, and communication channel capacity for efficient information transmission.

CO4: Analyze modern broadcast and radar communication systems, including colour television standards, radar architectures, modulation techniques, and signal processing methods for specific applications.

CO5: Evaluate satellite and specialized communication systems by analyzing orbital parameters, link budgets, multiple-access techniques, cellular communication standards, computer networks, and communication protocols.

2: Astrophysics & Cosmology-II

1. Star Formation & Early Evolution:

Observables & HR Diagram: Absolute/apparent magnitudes, color index, extinction, distance modulus, and stellar populations (Pop I, II, III) on the Hertzsprung-Russell diagram.

Cloud Collapse Physics: Jeans criterion (mass and length), isothermal vs. adiabatic collapse, free-fall and Kelvin-Helmholtz timescales.

Protostellar Evolution: Angular momentum removal (magnetic braking), brown dwarfs (deuterium burning limit), and pre-main-sequence tracks (Hayashi vs. Henyey).

2. Astrophysics of Planet Formation:

Protoplanetary Disks: Minimum Mass Solar Nebula (MMSN), temperature profiles, dust-to-gas ratio, viscous alpha-disk evolution, and snowlines/ice lines.

Planetesimal Formation: Aerodynamic drag (Epstein/Stokes regimes), dust settling, radial drift problem ("meter-size barrier"), pebble accretion, and the streaming instability.

Planet Assembly & Dynamics: Terrestrial runaway/oligarchic growth, core accretion vs. disk instability for giant planets, Type I/II orbital migration, and Kozai-Lidov resonances.

3. Stellar Structure, Thermodynamics & Transport:

Governing Equations: Hydrostatic equilibrium, mass continuity, energy balance, and composition gradients.

Atmospheres & Thermodynamics: Radiative transfer, optical depth, Saha ionization equation, spectral line formation, Rosseland mean opacity, and Schwarzschild convection criterion.

Structural Models & Stability: Polytropic spheres (Lane-Emden equation for n = 0, 1, 5), Eddington luminosity limit, homologous scaling, three characteristic timescales, and dynamical/secular stability.

4. Nuclear Astrophysics & Element Synthesis:

Kinetics & Burning Chains: Thermonuclear reaction rates, Gamow window, astrophysical S-factor, p-p chains, CNO cycle, and Schönberg-Chandrasekhar limit.

Advanced Burning & Heavy Elements: Triple-alpha process, 8Be bottleneck, advanced burning stages (C, Ne, O, Si), photodisintegration, and s-, r- and p-processes.

Particle Astrophysics: Solar neutrino problem (MSW flavor oscillations) and core-collapse supernova neutrino bursts.

5. Relativistic Astrophysics & Compact Objects:

Late Evolution: Red Giant Branch, AGB, planetary nebulae, white dwarfs (degenerate electron EOS, Chandrasekhar mass limit 1.44 M_{sun}, cooling mechanisms).

Neutron Stars & Transients: Neutronization, cold neutron EOS, Tolman-Oppenheimer-Volkoff (TOV) relativistic hydrostatic equation, pulsar spin-down models, novae, Type Ia, and core-collapse supernovae.

Black Holes: Schwarzschild and Kerr metrics, event horizons, ergosphere, Penrose process, and No-Hair theorem.

Recommended Textbooks:

1. Carroll, B. W., & Ostlie, D. A. — *An Introduction to Modern Astrophysics* (Cambridge University Press).
2. Padmanabhan, T — Theoretical Astrophysics (vol 1, 2) (Cambridge University Press)
3. Armitage, P. J. — *Astrophysics of Planet Formation* (Cambridge University Press).
4. Kippenhahn, R., Weigert, A., & Weiss, A. — *Stellar Structure and Evolution* (Springer).
5. Shapiro, S. L., & Teukolsky, S. A. — *Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects* (Wiley-VCH).
6. Choudhuri, A. R. — *Astrophysics for Physicists* (Cambridge University Press).
7. Iliadis, C. — *Nuclear Physics of Stars* (Wiley-VCH).
8. Perryman, M. — *The Exoplanet Handbook* (Cambridge University Press).
9. Hansen, C. J., Kawaler, S. D., & Trimble, V. — *Stellar Interiors: Physical Principles, Structure, and Evolution* (Springer).

COURSE OUTCOME:

1. Stellar Origins & Disks: We can calculate distance and evolutionary metrics on the HR diagram, evaluate cloud

collapse criteria, and model protoplanetary disk environments.

2. Planet Formation & Dynamics: We can analyze planetesimal accretion, overcome aerodynamic drift barriers, and evaluate giant planet formation and orbital migration.

3. Stellar Structure & Transport: We can solve governing stellar equations, model energy transport and opacities, and apply Lane-Emden polytropes to test stellar stability.

4. Nuclear Astrophysics & Synthesis: We can calculate thermonuclear reaction rates for fusion cycles, trace heavy-element synthesis (s-, r-, p-processes), and interpret neutrino signatures.

5. Compact Objects & Relativity: We can apply quantum degeneracy pressure, solve relativistic hydrostatic equations (TOV), and analyze black hole spacetime geometries.

3: Materials Science-II

Dielectric properties of materials:

Theory of electronic polarization and optical absorption, ionic polarization, orientational polarization. Optical phonon model in an ionic crystal; Interaction of electromagnetic waves with optical modes, Polaritons, Dispersion curves of transverse optical (TO) phonon and optical photon in a diatomic ionic crystal, LST relation; Metal-insulator transition.

Electrical properties of metals, semiconductors, ionic solids

Conductivity in metals, conductivity in semiconductors and effects of high fields, electrical conduction in ionic ceramics. Band gap determination in semiconductors using electrical and optical methods. Tensor Properties of Materials; Tensor representation of electrical conductivity.

Optical properties of Semiconductors: Direct and indirect semiconductors, interband transitions, Kramers-Kronig relations, Optical properties and band structure, Excitons, Frenkel excitons, Photoconductivity.

Mechanical Properties of metals and ceramics:

Concepts of stress & strain, stress-strain behavior, anelasticity, Plastic deformation, Hardness Knoop & Vicker's hardness test.

Phase transition in materials

Solid solutions, Phases, Thermodynamics of solutions, Phase rule, Binary phase diagrams, Binary isomorphous systems, Binary eutectic systems, ternary phase diagrams, kinetics of solid reactions.Order disorder phenomenon in binary alloys, long range order, super lattice, short range order.

Structure - Property correlation, Functional and smart materials

Correlation of structure with physical properties of materials, application prospects of materials in different areas. Solar Cells, Polymers, liquid crystals, luminescent and optoelectronic materials.

Books Recommended:

1. Elementary Solid State Physics by M. Omar Ali

2. Elements of X-ray diffraction by B. D. Cullity, Addison-Wesley Publishing Co.

3.. Crystallography applied to Solid State Physics, A.R. Verma, O.N. Srivastava, New-Age Publishers.

Course outcome

Students will have an understanding of different physical properties eg optical properties, dielectric properties, Electrical properties and mechanical properties of functional materials.

4: Condensed Matter Physics-II

Band theory: Introduction (Origin of continuous energy bands in crystalline solids, Valence band, Conduction band, Classifications of conductors, semiconductors, and insulators), Bloch's theorem and its general consequences, Band calculations: Orthogonalized Plane Wave (OPW), Augmented Plane Wave (APW) and Pseudopotential methods, The dynamics of electrons, Wannier functions and equations of motion in Wannier representation.

1. **Transport properties**: Boltzmann transport equation and its linearization, Relaxation time approximation, Temperature dependence of resistivity of a metal, Electron-phonon interaction, Limitations of the Boltzmann transport equation, Kubo formula for electrical conductivity, Transport coefficients of metals and semiconductors in presence of magnetic field.
2. **Magnetic properties:** Diamagnetism and paramagnetism of bound electrons, Angular momentum states in paramagnetic ions, Paramagnetic ions and crystal field theory, Quenching of orbital angular momentum, Pauli paramagnetism, Landau diamagnetism, Quantized magnetic energy levels in 3D, Quantum Hall effect, Magnetic ordering, The exchange Interaction, Direct and Indirect (R.K.K.Y. and Superexchange), Spin wave theory of ferromagnetism, Magnons, Spin waves in antiferromagnets, Anisotropy energy, Magnetic Domains.
3. **Optical properties:** The Complex dielectric function and the complex optical conductivity, Relation of complex dielectric function to observables, Drude theory–free carrier contribution to the optical properties, The interband transition process, Absorption of light in solids, the absorption coefficient, Direct interband transitions, Conservation of crystal momentum in direct optical transitions, Indirect interband transitions, Kramers-kronig relations, Optical properties and band structure, impurities and excitons, Mott-Wannier excitons, Frenkel excitons.

Books Recommended:

1. Basic Solid State Physics: Arun Kumar Raychaudhuri
2. Magnetism in Condensed Matter: Stephen Blundell
3. Condensed Matter Physics: Michael P. Marder
4. Solid State Physics An Introduction to Principles of Materials science: H. Ibach and H. Luth
5. Introduction to Solid-State Theory: Otfried Madelung

COURSE OUTCOME

This course is meant for students opting Condensed Matter Physics as "Major Elective", concluding the previous first course in condensed matter physics. An important part of the course is the dynamics of electrons in a crystal: a crucial element in the understanding of the electrical properties of crystals, particularly metals and semiconductors. In addition, transport properties and the emergence of magnetic order are discussed, concluding with optical properties. This course completes all the necessary background required for aspirant researchers in this field, and will provide students with the knowledge and expertise that is necessary to pursue doctoral studies in condensed matter physics.

5: Nuclear & Particle Physics-II

1. A brief overview of four fundamental interactions and their characteristics, elementary particles and their characteristics.

2. **Static model ($SU(3)_f$) of quarks:** Baryon and meson super-multiplets; basic quark model; Isospin and flavor symmetry; spin-flavor state functions of Baryon and meson super-multiplets; Color wave functions. Evidence for quark, color and gluon; calculation of charge and magnetic moments of baryons; drawbacks of $SU(3)_f$ quark model; Principles of discoveries of heavy flavors: Charm, bottom and top; SU(4) quark model; Vector mesons and their decays; Zweig rule.

3. Gauge symmetries of fundamental interactions: Concept of field, relation between particle and field. Lagrangian and various relativistic fields; Global and local gauge invariances; Noether's theorem; U(1) local gauge symmetry and QED; SU(2) local gauge symmetry and Yang-Mills fields; $SU(3)_c$ symmetries and QCD; Charge screening and anti-screening; running coupling constants; ultraviolet breakdown; asymptotic freedom; Infrared slavery.

4. Structure of Hadrons: High energy electron-proton elastic scattering - kinematics, differential cross-section; Rosenbluth formula. High energy electron-proton inelastic scattering - Bjorken variable; Electron-proton deep-inelastic scattering - differential cross-section and structure functions; Bjorken scaling and Callan-Gross relation; Naive Parton Model; Scaling violations and QCD improved Parton model.

5. Weak interaction: An analogy with electromagnetic interaction; Four-fermion point interaction; Weak interaction amplitude in terms of bilinear co-variants; V-A form of weak interaction; two-component theory of neutrino; parity violations in Λ^0, K^0 decays. Strangeness oscillation and regeneration phenomenon of K^0-mesons;

Neutrino mass and neutrino oscillation: Solar neutrino problem; derivation of the intensity of neutrino with time; experimental evidences of neutrino oscillations.

CP violation in B-mesons; Strangeness-conserving and strangeness-violating weak interactions; Cabbibo theory.

6. Gauge theory of weak interaction and Standard Model: Spontaneous symmetry breaking and mass generation; Goldstone theorem; Higgs mechanism; spontaneous breaking of SU (2) local gauge symmetry;

Electro-weak unification: Motivation for $SU(2)_L \times U(1)_Y$ gauge theory for electro-weak interactions; Glashow-Weinberg-Salam (GWS) model of electroweak symmetry breaking; combined covariant derivative; $W^{\pm}$ and Z^0 masses; the Standard model (SM) Hamiltonian.

Basic ideas of a Grand Unified Theory (GUT); variations of coupling constants with energy; SU(5) theory and its predictions; inclusion of gravity; Planck scale; brief chronology of events in the early universe.

Limitations of SM and GUTs; supersymmetry and supergravity.

Books recommended:

1. Modern Particle Physics - Mark Thomson (Cambridge University Press)
2. Introduction to High Energy Physics - D.H. Perkins, (Addison Wesley)
3. Introduction to Elementary Particles - David Griffiths (Wiley-VCH)
4. Quarks and Leptons: An introductory course in modern particle physics - F. Halzen and A.D. Martin (John Wiley & Sons)
5. An Introduction to Particle Physics - M.P. Khanna (PHI Learning)
6. Introduction to Quantum Electrodynamics and Particle Physics- D C Joshi (I. K. International Pvt. Ltd.)
7. An Introductory Course of Particle Physics-Palash B. Pal (CRC Press, 2015)

COURSE OUTCOME

After completing the course, the students will have an in-depth knowledge about strong and weak interactions. The students will have an overall knowledge on different types of weak interactions, parity violation as well as neutrino oscillation and solar neutrino problem. They will learn how to utilize gauge theories in determining the symmetry breaking in particle physics. This will be helpful for their future research work in theoretical high energy physics.

6: Laser Physics-II

1. Nonlinear Optics:

Introduction, nonlinearities of the polarization, generation of second harmonic, D.C., sum and difference frequency generation, anharmonic oscillator model, Miller's rule, coupled amplitude equations for SFM and SHG, Manley-Rowe relation, Basic idea of phase-matching, critical and noncritical phase-matching, quasi phase-matching method, effective nonlinear coefficient, parameters affecting doubling efficiency, OPO: threshold, output, efficiency, merits and demerits over other tunable lasers, UV-VIS-NIR crystals, assessment of nonlinear crystals (Kurtz powder

method), Chalcopyrite and IR crystals.

2. Higher Order Nonlinear Processes:

Four wave mixing processes, third harmonic generation, resonance enhancement of nonlinear susceptibilities, stimulated Raman scattering.

3. Ultrafast Phenomenon: Mode-locking: pico second and femtosecond pulse generation, Basic concepts for measurement of fast processes, Streak technique, Stroboscopes, nonlinear optical methods for measuring ultrashort pulses, different applications.

4. Optical communication:

Optical fibre waveguide, Electromagnetic analysis of simple optical waveguide: Basic waveguide equation, Group velocity dispersion and dispersion compensation, pulse distortion and information rate in single mode and multimode optical fibres, fibre losses, coupling of sources with fibre, modulation, PCM, multiplexing, WDM, TDM, Solitons.

5. Laser cooling & BE Condensation:

Principle of laser cooling & trapping, optical molasses, cooling below Doppler limit, magnetic trapping, applications.

6. Laser in medical science:

Laser tissue interaction, physical effects on human skin of laser beam reflection, absorption, scattering, different interaction mechanism, different surgical treatment.

7. Chemical Application:

Selective excitation reaction, different separation processes, principle of isotope separation, uranium enrichment.

8. Laser speckle:

Spatial frequency filtering- principle and its applications.

Books Recommended:

1. Handbook of Nonlinear Optics- R L Sutherland
2. Solid State Laser Engineering- W Koechner
3. The Principle of Nonlinear Optics- Y R Shen
4. Optical Fiber Communications - Gerd Keiser

COURSE OUTCOME

On successful completion of the course, the students:

1. Will have good understanding on how one can obtain suitable widely tunable coherent sources in both ultraviolet as well as infrared regions of electromagnetic spectrum utilizing lowest order nonlinear effects in different materials and also how the tunability of the existing lasers can be extended using the same processes. They will have the knowledge of OPO and its utilization. They will learn about some important nonlinear crystals required for extending tunability of different commercial lasers.

2. Will have basic understanding of higher order nonlinear effects and their utilization.

3. Will have the knowledge of ultrafast phenomena and how to generate ultrashort laser pulses using different techniques. They will also learn how to estimate ultrashort pulse widths by nonlinear optical technique. They will also have basic concept of Soliton.

4. Will learn details of optical fiber communications which will give them knowledge on single mode, step index, GRIN fibers, their communication specifications, multiplexing through WDM and TDM. They will also have a basic understanding on application of Soliton in optical communication.

5. Will learn details of Bose-Einstein condensation and how to achieve cooling below Doppler limit using magnetic trapping.

6. They will have the basic knowledge of chemical application of lasers that will include the process of laser isotope separation.

7. They will gain knowledge on medical application of lasers through laser tissue interaction as well as different surgical treatments by lasers.

8. The students will also get an idea about the spatial filtering process studying this paper.

Course code: PG1 PHYS 2014

Term Paper/ Project work

Course code: PG1 PHYS 2015 (Advanced General Practical)

List of Experiments

Group A:

1. Determination of temporal coherency of a coherent (laser) light and compare it with incoherent light (sodium)
2. Study of magneto-optic effect (Faraday effect)
3. Study of electro-optic effect (Pockels effect)
4. Measurement of bending loss in a multi-mode optical Fiber.
5. Study of characterization of antenna
6. Design of active filters (a) band-pass filter, (b) all pass filters
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Studies on LED modulation characteristics
9. Arc emission and absorption measurements using CCD based Constant Deviation Spectrometer.

10. Band gap evaluation of a semiconductor by studying temperature variation of resistance.

Group B:

1. Study of ultrasonic diffraction using a laser

2. Study of gamma ray spectrum of radioactive nuclides with NaI (Tl) scintillators & SCA
3. Study of beta-ray absorption & determination of mass absorption co-efficient of the given absorber material.
4. Study of gamma-ray absorption & determination of gamma ray energy
5. Determination of particle size of an unknown powder specimen using Scherrer equation from supplied XRD pattern
6. Phase identification of an unknown sample from its X-ray diffraction pattern
7. Identification of liquid, solid or powder samples using Laser Raman Spectrometer.
8. Study of NMR.
9. Intensity dependent nonlinear susceptibility of nonlinear liquid by Z-Scan technique.
10. Determination of grove spacing of a CD by diffraction method and hence determination of wavelength of unknown source.

COURSE OUTCOME

This course contains some state of the art experiments for introducing students to the modern research laboratories. The students are highly benefited from these experiments some of which are even used by our research scholars. This course contains experiments from different areas in Physics which enables students to have an overall exposure to the advanced level of equipment and technologies.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

OPTION- III: Only Research Thesis/ Project in 1st & 2nd Semesters

SEM	Course Type	Code & Level	Name of the Course	Credit	L – T - P	Marks	Marks Dist. Th. – Pr. - IA
III	Research Thesis/ Project	**PG2 PHYS 1031 (500-599)**	Research Thesis/ Project	20	0-0-20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (4 credits, 50 Marks) & Viva-voce (4 Credits, 50 Marks,)- 8 Credits, 100 Marks
IV	Research Thesis/ Project	**PG2 PHYS 2031 (500-599)**	Research Thesis/ Project	20	0-0-20	250	0-250-0 Preparation & Submission of Research Thesis/ Project Report (12 Credits)-150 Marks, Seminar Presentation (4 credits, 50 Marks) & Viva-voce (4 Credits, 50 Marks,)- 8 Credits, 100 Marks
	Two-credit Compulsory Course	**PG2 PHYS 2041 (500-599)**	Community Engagement	(This shall not be taken into consideration in the calculation of SGPA and CGPA)			
	Total			**40**		**500**	
Grand Total				**90**		**1250**	