Revised Course / Curriculum / Syllabus in compliance of NEP-2020 (M. Sc.)

M. Sc. in Physics

Program Learning Objectives:	Program Learning Outcomes:
Program Goal 1: Prepare and aid the students in acquiring strong foundation in various Physics subjects	Program Learning Outcome 1a: Strong fundamentals in core Physics Program Learning Outcome 1b: Problem solving skills and temperament using Physics
Program Goal 2: Provide specialized knowledge in core and applied areas of Physics	Program Learning Outcome 2a: Specialized knowledge to pursue further work in theoretical Physics Program Learning Outcome 2b: Specialized knowledge to pursue further work in experimental Physics
Program Goal 3: Prepare and aid the students for a career in Physics that may include one or more of the following: a school/college teacher in Physics, research staff in lab / industry, eligibility for pursuing a higher degree and a career in academia / industry, science communicator / science journalism, etc.	Program Learning Outcome 3: Strong problem-solving skills, troubleshooting ability, ability to understand and formulate problem statements, construct models/experiments to provide insights into the problem.

Semester-I

Sl. No.	Subject Code	Course Name	L	T	P	C
1.	PH4101	Mathematical Physics-I	3	1	0	4
2.	PH4102	Classical Mechanics	3	1	0	4
3.	PH4103	Quantum Mechanics-I	3	1	0	4
4.	PH4104	Numerical Techniques	2	0	2	3
5.	PH4105	Electronics	3	0	4	5
6.	HS4111	Soft-Skills for Employability	1	2	0	3
		Total	**15**	**5**	**6**	**23**

Semester-II

Sl. No.	Code	Course Name	L	T	P	C
1.	PH4201	Electrodynamics-I	3	1	0	4
2.	PH4202	Statistical Physics	3	1	0	4
3.	PH4203	Modern Optics	3	0	4	5
4.	PH4204	Introduction to Nuclear and Particle Physics	3	0	0	3
5.	PH42XX	Department Elective-I	2	1	0	3
		Total	**14**	**3**	**4**	**19**

Semester-III

Sl. No.	Subject Code	Course Name	L	T	P	C
1.	PH5101	Atomic and Molecular Physics	3	1	0	4
2.	PH5102	Condensed Matter Physics-I	3	0	0	3
3.	PH5103	Atomic, Molecular and Nuclear Physics Laboratory	0	0	4	2
4.	PH51XX	Department Elective - II	X	X	X	3*
5.	XX61PQ	Inter-Disciplinary Elective - I	3	0	0	3*
6.	PH5199	Project - I	0	0	12	6
		Total				**21**

Semester-IV

Sl. No.	Code	Course Name	L	T	P	C
1.	PH5201	Condensed Matter Physics Lab	0	0	4	2
2.	PH52XX	Department Elective - III	X	X	X	3*
3.	PH52XX	Department Elective - IV	X	X	X	3*
4.	XX62PQ	Inter-Disciplinary Elective II	3	0	0	3
5.	IK5201	Indian Knowledge Systems	2	0	0	2
2.	PH5299	Project II	0	0	16	8
		Total				**21**

Total Credits: 84

* The values for L-T-P may change depending on nature of course with final credit remaining fixed at 3. However, the total credit for electives has to be maintained. Electives can be floated in either semester; the course code will be PHX1XX, and PHX2XX for the same elective running in odd and even semester, respectively.

Theme Based Elective Groups

Themes:
Theme 1: General Electives
Theme 2: Condensed Matter Physics and Materials Science
Theme 3: Optics and Photonics
Theme 4: High-energy Physics and Cosmology
Theme 5: Quantum Information and Quantum Techniques

Sl. No.	Subject Code	Departmental Elective – I	L	T	P	C
1.	PH4205	Quantum Mechanics-II	2	1	0	3
2.	PH4206	Thin Film Technology	3	0	0	3
3.	PH4207	Introduction to Medical Physics	2	1	0	3
4.	PH4208	Introduction to Data Science for Physicists	2	1	0	3

Sl. No.	Subject Code	Departmental Elective - II	L	T	P	C
1.	PH5104	Electrodynamics-II	3	0	0	3
2.	PH5105	Nanophotonics	2	1	0	3
3.	PH5106	Nanoscience	2	1	0	3
4.	PH5107	Quantum Theory of Collisions	2	1	0	3
5.	PH5108	Introductory Biophysics	2	1	0	3
6.	PH5109	Spintronics	2	1	0	3
7.	PH5110	Magnetism at Nanoscale	2	1	0	3
8.	PH5111	Mathematical Physics-II	2	1	0	3
9.	PH5112 /PH5208	Introduction to Nonlinear Dynamics and Chaos	3	0	0	3
10.	PH5113 /PH5219	Quantum Field Theory	2	1	0	3
11.	PH5114	Physics of Ultracold Atoms	2	1	0	3

Sl. No.	Subject Code	Departmental Elective – III	L	T	P	C
1.	PH5202	General Relativity and Cosmology	2	1	0	3
2.	PH5203	Nanoelectronics	2	1	0	3
3.	PH5204	Measurement Techniques	2	0	2	3
4.	PH5205	Quantum Optics & Quantum Information	2	1	0	3
5.	PH5206	Quantum Transport in Mesoscopic Systems	2	1	0	3
6.	PH5207	Condensed Matter Physics-II	3	0	0	3
7.	PH5208 /PH5112	Introduction to Nonlinear Dynamics and Chaos	3	0	0	3
8.	PH5209	Ultrafast Optics and Spectroscopy	2	1	0	3
9.	PH5210	Magnetism: Fundamentals to Application	2	1	0	3
10.	PH5211	Ferroic Phenomena	2	1	0	3
11.	PH5212	Materials for Engineering Applications	2	1	0	3

Sl. No.	Subject Code	Departmental Elective - IV	L	T	P	C
1.	PH5213	Nanoionics: Concepts and Technological Applications	3	0	0	3
2.	PH5214	Computational Physics	2	0	2	3
3.	PH5215	Scanning Probe Microscopy	2	1	0	3
4.	PH5216	Biophotonics	2	1	0	3
5.	PH5217	Magnetic Materials and Applications	2	1	0	3
6.	PH5218	Fourier Optics and Holography	2	1	0	3
7.	PH5219 /PH5113	Quantum Field Theory	2	1	0	3
8.	PH5220	Particle Physics	2	1	0	3
9.	PH5221	Soft Matter Physics	3	0	0	3
10.	PH5222	Quantum Materials	2	1	0	3
11.	PH5223	Low Temperatures Techniques	2	0	2	3

*An upgraded version of M. Sc. 5/6 level electives need to be essentially upgraded for PhD students with additional content comprising additional lectures / assignments / tutorials / miniproject making the total credit : 3-1-0-4 / 3-0-2-4. Such course proposals with an advanced level (6/7 level course number) are listed separately for PhD students.

List of Inter Disciplinary Electives (IDEs) – For students other than Dept. of Physics

Sl. No.	Subject Code	Subject	L	T	P	C
1.	PH6101/6201	Physics of Complex Systems	3	0	0	3
2.	PH6102/6202	Physics of Nanoscience	3	0	0	3
3.	PH6103/6203	Semiconductor Processing: An Interdisciplinary approach	3	0	0	3

Sl. No.	Subject Code	Course Name	L	T	P	C
1.	PH4101	Mathematical Physics-I	3	1	0	4
2.	PH4102	Classical Mechanics	3	1	0	4
3.	PH4103	Quantum Mechanics-I	3	1	0	4
4.	PH4104	Numerical Techniques	2	0	2	3
5.	PH4105	Electronics	3	0	4	5
6.	HS4111	Soft-Skills for Employability	1	2	0	3
		Total	**15**	**5**	**6**	**23**

Course Number	PH4101
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Mathematical Physics-I
Learning Mode	Lectures & Tutorials
Learning Objectives	The purpose of the course is to introduce students to methods of mathematical physics and to develop required mathematical skills to solve problems in quantum mechanics, electrodynamics and other advanced courses in physics.
Course Description	The first half of the course is focused on the basics of vector and tensor algebra used in solving problems in physics and complex analysis. The second half of the course focuses on the differential calculus with the emphasis on learning techniques to solve the ordinary differential equations and partial differential equations.
Course Outline	Linear Vector space - Eigenvalues and Eigenvectors, Similarity transformations, diagonalization. Special matrices: Orthogonal, Hermitian and Unitary matrices. Cayley-Hamilton theorem. Hilbert space. Complex analysis: - Basic review, Cauchy's integral theorem, Conformal mapping, Classification of singularities, Residue theorem. Contour integration and examples. Analytic continuation. Multiple-valued functions, branch points and branch cut integration. Introduction to tensor – contravariant and covariant tensor, covariant derivative, Metric tensor, Raising and Lowering of indices, examples of Rank 1 tensor (four vectors: 4-momentum and 4-force). Ordinary differential equations of first & second order, Power series solutions for second-order ordinary differential equations. singular points of ODEs, Wronskian Sturm-Liouville problems. **Partial Differential Equations: -** Laplace and Poisson equation, Wave equation, Heat Equation. Green's function approach and inhomogeneous differential equations. Integral transforms: - Fourier series, Fourier and Laplace transforms, Parseval's theorem, Convolution theorem and applications.
Learning Outcome	Complies with 1b, 3
Assessment Method	Mid-term Examination, End-term Examination, Quiz & Assignments
Textbooks:	• George B. Arfken and Hans J. Weber, Mathematical Methods for Physicists, Academic Press Inc., 4th Edition, 1995. • I.A. Gradshteyn, I.M. Ryzhik, 6thEdition, Academic Press, 2000. • M. Abramowitz and I. A. Stegan, Mandbook of Mathematical Functions, Dover Publications,INC., New York, 1965.
References:	• E. Kreyszig, Advanced Engineering Mathematics, Wiley India, 8thEdition, 2008. • A.W. Joshi: Matrices and Tensors in Physics, New Age, 1995. • Mathematics for Physicists, P. Dennery and A. Krzywicki, Dover, New York, 1996. • Mathematics of Classical and Quantum Physics, F. W. Byron, Jr. and R. W. Fuller, Dover, New York, 1992

Course Number	**PH4102**
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Classical Mechanics
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with Program Goals 1, 2a and 3
Course Description	Formulate mechanics problem with Lagrangian, Hamiltonian, Calculus and Jacobi methods. Solve central force motion, rigid body dynamics, relativistic problems with learned expertise.
Course Content	Review of Lagrangian and Hamiltonian formalisms in various systems, Legendre transforms, Principle of least action, Hamilton's canonical equations and their applications. Symmetries, Noether theorem and conservation laws. Canonical transformations, Infinitesimal Canonical transformation, Integral invariant of Poincare; Lagrange and Poisson brackets and their applications. Liouville's theorem; Hamilton-Jacobi equation, Action and angle variable and their applications; Harmonic oscillator and Central Force problems. Dynamical Systems, Phase space dynamics Special theory of relativity: - Lorentz transformations, length contraction and time dilation, velocity addition formula, relativistic kinematics and mass-energy equivalence. Lagrangian and Hamiltonian for relativistic particle. Two body Collisions - scattering in laboratory and Centre of mass frames, Small oscillations and normal modes, Rigid body motion, Euler's equations and applications, Precession and nutation.
Learning Outcome	Complies with PLO 1, 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Classical Mechanics - H. Goldstein, C. P. Poole and J. Safko; Pearson Education, 2011. • Classical Mechanics - J. R. Taylor, University Science Books, 2005. • Introduction to Special Relativity - Robert Resnick; Wiley, 2007.
References:	• Classical Mechanics, L. D. Landau and E. M. Lifshitz, Course on Theoretical Physics, Vol.1, 3rd Edition, Butterworth-Heinemann. • Classical Mechanics, N.C. Rana and P. S. Joag, McGraw Hill Education Pvt Ltd., 2001. • Introduction to Dynamics, I. Percival and D. Richards, Cambridge University Press, 1983. • Special Relativity - A.P. French; CRC Press, 2017. • Classical Mechanics, Jose and Saletan • Calculus of Variation, Gelfand and Fomin

Course Number	**PH4103**
Course Credit (L-T-P-C)	3–1–0–4
Course Title	Quantum Mechanics-I
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	This course provides fundamentals of modern Quantum Mechanics starting with 1-D, 3-D problems that extends to angular momentum algebra, perturbation theory and Variational techniques.
Course Content	Physical implications of the Schrödinger equation, derivation of Ehrenfest's theorem; Quantum operators & generators, orthonormal & complete basis, quantum superposition, generalized uncertainty principle; Observables and quantum measurements; Solution of Schrodinger equation for 1D solvable potentials: harmonic oscillator, raising and lowering operators, Angular momentum algebra, angular momentum & rotations, matrix representation, ladder operators; orbital & spin angular momentum, Eigen functions of orbital angular momentum, 3D problems: hydrogen atom, Harmonic oscillator, Particle in 3D box, Stern-Gerlach experiment, spin-1/2 system, Pauli matrices; addition of angular momenta, Clebsch-Gordan coefficients, spin-orbit coupling. Variational technique: Helium atom; WKB Approximation, Stationary perturbation theory, first and second order corrections, application to one-electron system. Stark effect, normal & anomalous Zeeman effect. Introduction to quantum computing.
Learning Outcome	Complies with PLO 1, 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Quantum Mechanics (Vol-I), C. Cohen-Tannoudji, B. Diu, F. Laloẽ, John Wiley & Sons, 2005. • Modern Quantum Mechanics, J. J. Sakurai, Pearson Education, 2002. • Quantum Mechanics, L. I. Schiff, McGraw-Hill, 1968.
References:	• Principles of Quantum Mechanics, R. Shankar, Springer, 2008. • Quantum Physics, S. Gasiorowicz, Wiley, 2007. • Quantum Mechanics, E. Merzbacher, John Wiley, 1999. • Quantum Mechanics, V.K. Thankappan, Wiley Eastern, 1985. • The Feynman Lectures on Physics, Vol.3, R.P. Feynman, R.B. Leighton and M.Sands, Narosa Publ. House, 1992. • The Principles of Quantum Mechanics, P.A.M. Dirac, Oxford Univ. Press, 1991. • Quantum Mechanics -Nonrelativistic Theory, L.D. Landau and E.M. Lifshitz, 3rdEdition, Pergamon, 1981. • Introduction to Quantum Mechanics, D. J. Griffiths, Pearson Education, 2005. • Quantum Mechanics, B. H. Bransden and C. J. Joachain, Pearson Education 2ndEd., 2004. • Barton Zweibach, Quantum Mechanics, MIT Press, 2021.

Course Number	**PH4104**
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Numerical Techniques
Learning Mode	Lectures & Laboratory
Learning Objectives	To make students solve physics related problems using basic and advanced numerical techniques. Initially, the course aims to develop computer programing skills in students so that they can develop logics and algorithm suitable to solve a problem.
Course Description	The student will learn solving system of linear equations, interpolation, extrapolation, numerical differentiation, integration, root finding, solving ODE and PDEs etc. The course discusses various techniques to accomplish the above mentioned tasks in the class room. In parallel, the students will develop code by themselves in the computational laboratory. Theory + lab session on a particular topic will give students a complete understanding.
Course Outline	Computer programming: Algorithm, flowchart, structure of program Solution of linear algebraic equation: Gauss-Jordan elimination, LU and Cholesky decomposition; Interpolation and extrapolation: Polynomial, Rational functions, Application in two or more dimension; Numerical integration: Romberg, Gaussian Quadration and Orthogonal polynomials; Numerical differentiation of functions; Root finding and nonlinear sets of equations: Bisection, Secant, Regula-Falsi method, Newton Raphson method, Roots of polynomial, Globally convergent method for nonlinear systems of equations; Minimization or maximization: Golden section search, Parabolic and Brent's method, Downhill simplex, Conjugate gradient method; Eigensystems: Jacobi transformation, Eigenvalue and eigenvector, Hermitian, Reduction to Hessenberg form; FFT in two or more dimensions; Least square method and non-linear models; Integration of ODE: Runge-Kutta and Predictor-Corrector method, Crank-Nicolson Method; split step, Two point boundary value problems; Integral equation: Linear Regularization and Backus-Gilbert method; PDE: Flux-conservative method for initial value problem, Relaxation-method for boundary value problem.
Learning Outcome	Complies with PLO 1B, 3
Assessment Method	Mid-term written examination (30%), Mid-term lab examination (15%), End-term written examination (30%), End-term lab examination (15%), Assignment & Quiz (10%)
Suggested Readings:	
Text book	• Y. Kanetkar, Let us C, 13th Edition, BPB publ., 2013. • W. H. Press, S. A. Teukolsky, W T. Vetterling and B. P. Flannery, Numerical Recipes in C: The Art of Scientific Programming, 2nd Edition, Cambridge Univ. Press, 1997.
References:	• M. K. Jain, S. R. K. Iyengar and R. K. Jain, Numerical Methods for Scientific and Engineering Computation, 6th Ed., New Age Int.(P) Ltd., 2014 • B. S. Grewal, Higher Engineering Mathematics, 43rd Edition, Khanna Publishers, 2014. • Let Us C, Yashavant P. Kanetkar, Infinity Science Press; 8th Edition, 2008. • Let Us C++, Yashavant P. Kanetkar, BPB, 2003. • Programming in ANSI C, Tata McGraw-Hill Education, 2008. • Programming with C (Schaum's Outlines Series), McGraw Hill Education (India) Private Limited; 3rd Edition, 2010. • The C++ Programming Language, Addison Wesley; 4th Edition, 2013.

Course Number	**PH4105**
Course Credit (L–T–P–C)	3-0-4-5
Course Title	Electronics
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	The course has essentially two parts: Analog Electronics and Digital Electronics. In the beginning, emphasis is given to pick up skill on analyzing any kind of circuit. After that, the pupil is introduced to the semiconductor device physics. Further on, the analog electronic circuits made of these devices are introduced and ways to analyze those. Lastly, digital electronics is discussed briefly. Familiarizes the students with the electronics laboratory, electronic and electrical components, circuit design, measurement equipment's etc. which allows them to apply this knowledge in both research and industrial scenarios.
Course Outline	Module 1: Recap of network theorems. Module 2: Ohmic and rectifying contacts, p-n junctions, Applications including Varactors, Zener diode, Schottky diode, switching diodes, Tunnel diode, Light emitting diodes, Photodiodes, Solar cell, h-parameter analysis; Voltage amplifiers; Darlington pair; Field effect transistor action: MOSFETS. Module 3: Differential Amplifier, Instrumentation and operational amplifiers; Op-Amp Circuits: Characteristics of ideal and practical op-amp; inverting, noninverting and differential amplifier, Basic characteristics with detailed internal circuit of IC Op-Amp; Active filters; Nonlinear amplifiers using Op-Amps-log amplifier, anti-log amplifier, regenerative comparators; ADC and DAC circuits; Op-amp based self-oscillator circuits- RC phase shift, Wien bridge, non-sinusoidal oscillators. Module 4: Logic functions and Digital circuits; Karnaugh maps; SOP and POS design of logic circuits; MUX as universal building block; RCA, CLA and BCD adder circuits; ADD-SHIFT and array multiplier circuits; RS, JK and MS-JK flip-flops; registers and counters. List of experiments: 1. Introduction to Electronics laboratory 2. Study of Silicon Controlled Rectifier (SCR) Characteristics 3. Study of Junction Field Effect Transistor (JFT) Characteristics 4. Study of Unijunction Transistor (UJT) Characteristics 5. Designing of a Common Emitter (CE) Amplifier 6. Study of Operational Amplifier (Op-Amp) and Its Applications 7. Designing of Active Filters using Op-Amp 8. Designing and Analysis of Colpitts oscillator and A Stable Multivibrator (IC – 555) 9. Boolean Algebra: Study of Logic Gates and Verification of De Morgan's Theorem 10. Combinational Logic: Adder and Subtractor Circuit Design 11. Sequential Logic: RS and JK Flip Flop Circuits Design. Design and Fabricate a PCB Board.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3
Assessment Method	Mid-semester examination and End-semester examination (Theory) Experimental reports and viva to access the day to day performance, Mid-semester examination and End-semester examination (lab)
Suggested Readings:	Text books • Digital Principles and Applications, D. P. Leach, A. P. Malvino, G. Saha, 8th Edition McGraw Hill India Pvt. Ltd, 2015 (ISBN-13: 978-93-3920-340-5).

	• Electronic Devices and Circuit Theory, R. L. Boylestad and L. Nashelsky, 11th Edition, Prentice Hall, 2012 (ISBN-13: 978-0132622264). • Solid State Electronics Devices, B. G. Streetman and S. K. Banerjee, 7th Edition, Prentice Hall of India, 2014 (ISBN-13: 978-8120350007) • Fundamentals of Electrical Engineering, L. S. Bobrow, Asian Edition, Oxford University Press, 2013 (ISBN-13: 978-0198086895) • Integrated Electronics: Analog and Digital Circuits and Systems, J. Millman and C. C. Halkias, 2nd Edition, McGraw Hill Education, 2017, ISBN-10: 9780070151420 • Op-Amps and Linear Integrated Circuits, R. A. Gayakwad, 4th Edition, Pearson Education, 2016 References • Electronic Principles, A. P. Malvino and D. J. Bates, 7th Edition, McGraw Hill India Pvt. Ltd, 2014 (ISBN-13: 978-0-07-063424-4).

Course Code	**HS4111**
Course Credit	L-T-P-C: 1-2-0-3
Course Title	Soft Skills for Professional Development
Learning Mode	Lectures and Tutorials
Learning Objectives	**Soft Skills**. These are the traits, characteristics, habits, and skills needed to survive and thrive in the modern work world. This **soft skills** course will teach you how to develop the skills that can make the difference between a lackluster career that tops out at middle management versus one that lands you in the executive suite or wherever you define career success. This course aims to help the students **(a)** gain a comprehensive understanding of communication skills for work place interaction; **(b)** attain proficiency in written and oral language; **(c)** develop team work skills; **(d)** foster decision making; **(e)** strengthen analytical and thinking skills; **(f)** develop leadership skills; **(g)** acquire techniques for time management, problem solving and emotional intelligence.
Course Description	This academic course on soft skills aims to equip students with skills necessary for the professional world. By focusing on essential principles and providing practical experiences, students develop their soft skills. Through interactive discussions and exercises, students enhance critical thinking and adaptability in diverse contexts. Upon completion, students will excel in formal presentations, group discussions, and persuasive writing, enhancing their verbal and non-verbal proficiency.
Course Outline	**Section A: Theoretical Component** **Unit 1: Communication skills** Barriers to communication – Verbal communication (oral and written) – Non-Verbal Communication – interpersonal communication – email etiquette – power to listen – ethical considerations in communication – intercultural communication – comprehension – creative and critical writing (included in section B-below) **Unit 2: Team Building** Conflict resolution – Mediation – Accountability – Collaboration – Empathy - building rapport – cultural awareness – Dealing with people - group and teams, group formation, group decision making, types of teams and the models of team effectiveness – Negotiation techniques **Unit 3: Leadership** Leader vs Managers – Core values of leadership - leadership styles – Theories of Leadership – Leadership models - Vision and its articulation and implementation – goal setting and performance management – Ethical leadership – Power -power bases -power tactics **Unit 4: Personality Development and Stress Management** Theories of Personality development (Freud, Jung, Eysenck, Carl Rogers and Maslow), Personality frameworks such as MBTI, Big Five and personality assessment - Reasons and Remedies of Stress. **Unit 5: Thinking** Critical Thinking - Reasoning: Deductive and Inductive – Analytical skills – brainstorming – strategic thinking – creative thinking – Lateral Thinking – EQ and IQ **Unit 6: Problem Solving** What is a problem? Identifying a problem – data collection methods and tools – 5 Whys – drill down technique – case and effect diagram Prioritizing problem – Pareto's principle Generating solutions – making decisions - Implementing solutions Evaluating solutions **Unit 7: Time Management** What is Time Management?

	Time Management Strategies Stumbling Blocks in Time Management Task Prioritization and Delegation Technology and Time Management **Section B: Tutorial Component** Unit I: Group Discussion Unit II: Oral presentation Unit III: Designing and Using PPTs – solo and group presentation Unit IV: Critical writing practice Unit V: Analytical writing practice

Sl. No.	Code	Course Name	L	T	P	C
1.	PH4201	Electrodynamics-I	3	1	0	4
2.	PH4202	Statistical Physics	3	1	0	4
3.	PH4203	Modern Optics	3	0	4	5
4.	PH4204	Introduction to Nuclear and Particle Physics	3	0	0	3
5.	PH42xx	Department Elective-I	2	1	0	3
		Total	**14**	**3**	**4**	**19**

Course Number	**PH4201**
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Electrodynamics-I
Learning Mode	Lectures & Tutorials
Learning Objectives	To impart knowledge on the concepts of electrostatics, magnetostatics and their applications. Introduce Maxwell's equations and discuss their applications to propagation of electromagnetic waves in free space and in conducting medium. Introduce the concepts of wave-guides and optical fibers.
Course Description	The course focuses on review with mathematical rigour of electrostatics and magnetostatics. In depth discussion on Maxwell's equations and their applications to propagation of electromagnetic waves in free space and conducting medium. It will also cover the discussions on wave-guides and optical fibers.
Course Outline	**Review of Electrostatics and Magnetostatic:** Gauss's law, Poisson's and Laplace Equation, Multipole expansion, Biot-Savart's Law, Ampere's circuital Law, Continuity equation. Boundary value problem for E and B. Vector and scalar potentials formulation, Gauge invariance and gauge fixing, Coulomb and Lorentz gauge. **Maxwell's Equation:** Maxwell's Equation, Green's function solution of Maxwell's eq, Energy stored in an electric and magnetic field, Poynting's theorem and Energy density, Conservation laws and Maxwell's stress tensor. **EM wave propagation:** Plane waves in free space, transverse nature of EM waves, refractive index and dielectric constant, wave impedance, polarization, susceptibility, magnetization. Plane waves in dispersive media, Lorentz model, dispersion, absorption, phase velocity, group velocity. Boundary conditions at a plane interface between two media. Reflection & Refraction of plane waves at plane interface between two dielectric media, Laws of Reflection & Refraction. Fresnel's Formula for perpendicular & parallel polarization, Brewster's law, Total internal reflection, Polarization (linear & circular), Stoke's parameter. Plane waves in conducting media, relaxation time, skin depth. Electrical conductivity of ionized gases, plasma frequency, EM wave propagation through ionosphere **Guided Waves:** TEM waves and propagation of TE and TM waves, Rectangular and coaxial wave-guides, Energy propagation in guided waves, Resonant Cavities, Q-factor
Learning Outcome	Complies with PLO 1b, 3
Assessment Method	Mid-term Examination, End-term Examination, Quiz & Assignments
Suggested Readings:	
Textbooks:	• Introduction to Electrodynamics - D J. Griffiths, Pearson Education, 2006. • Electromagnetics - B. B. Laud, New Age International (P) Limited, 1987. • Classical Electrodynamics - J. D. Jackson; Willey, 1999. • Modern Electrodynamics – A. Zangwill
References:	• (i) Electrodynamics of Continuous Media & (ii) Classical theory of fields - L.D. Landau and E.M. Lifshitz; Butterworth-Heinemann 1984 & 1987. • Classical Electrodynamics - Walter Greiner, D. Allan Bromley, Sven Soff; Springer, 1998. • The Feynman Lectures On Physics: Vol II - R. P. Feynman; Pearson .Education India (2012)

	• Foundations of Electromagnetic Theory - J.R. Reitz, F.J. Milford & R. W. Christy; Narosa, 1979. • Principles of Electrodynamics - Melvin Schwartz; Dover, 2003.

Course Number	**PH4202**
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Statistical Physics
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	Equips the students with the techniques in Statistical Physics and allows them to apply these techniques to wide variety of problems in Physics
Course Content	Review of Probability techniques using Random walk as example, Diffusion; distribution functions; Phase space; Postulates of Statistical Physics; Ergodicity, Equilibrium and steady-state; Microcanonical ensemble approach with Ideal gas, two-level systems and localized moment as examples; Canonical formalism, Partition functions and real gases; derivation of van der Waals equation of state; Density-matrix formalism, Ising model, Grand-canonical ensemble approach; Spin-statistics theorem; Quantum statistics: Bosonic and Fermionic gases; Fugacity; Bose-Einstein Condensation, Phases and phase transformations, Ehrenfest criteria, order-parameters and idea of spontaneous symmetry breaking; Ice-water-vapor, Maxwell's construction, liquid Helium as example; Time series; Langevin and Master's equation; Boltzmann transport equation and its solution within relaxation time; Statistical Mechanics of Learning
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• F. Reif, Fundamentals of Statistical and Thermal Physics, Levant Books, 2010. • K. Huang, Introduction to Statistical Physics, Chapman and Hall/CRC, 2ndEdition, 2009. • R. K. Pathria and Paul D. Beale, Statistical Mechanics, Elsevier, 3rd Edition, 2011.
References	• F. Mandl, Statistical Physics, Wiley-Blackwell, ELBS Edition, 1988. • D. Chandler, Introduction to Modern Statistical Physics, Oxford Univ. Press, 1987. • M.Pilschke and B.Bergerson, Equilibrium Statistical Physics, World Scientific, 1994. • B. P. Agarwal ad M. Eisner, Statistical Mechanics, Wiley Eastern Limited, 1988. • Carolyne M. van Vliet, Equilibrium and Non-equilibrium Statistical Mechanics, World Scientific, 2008.

Course Number	**PH4203**
Course Credit (L-T-P-C)	3-0-4-5
Course Title	Modern Optics
Learning Mode	Lectures and Lab
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course provides fundamental working principles of Lasers, Nonlinear optics, Optical technologies and various modern cutting edge optical techniques. In lab course, the students need to perform several experiments related to fundamental and applied physics.
Course Outline	Interference, Basics of white light interferometry, Anti-reflective coating, Kirchoff's integral, Fresnel and Fraunhoffer diffraction, Ellipsometry technique and its applications Laser fundamentals: Einstein's coefficients, spontaneous and stimulated emission and absorption, Population inversion, spectral broadening, Properties of the lasers: Coherence-Spatial and temporal, directionality, mono-chromaticity, spectral density, Amplification of stimulated emission inside a laser cavity, Photon density of states, Rate equations, three and four level lasers. Single mode and Multimode lasers, Intensity and wavelength stabilization techniques, Tunable lasers and their applications in spectroscopy, Pulsed lasers - Industrial and Medical applications, Quantum cascaded laser, Wave propagation in anisotropic media, Concept of negative refractive index and its application in metamaterials, Harmonic Generations, self-focusing, parametric down conversion Basics of holography, Applications of Holography, Holographic Optical Elements, Digital holography, Optical Information Security Introduction to Fiber optics, Types of optical fibers, Single and Multimode fibers, Losses in optical fibers, Fiber-optic devices, Optical receivers Pulse propagation in fibers, Group velocity dispersion, Introduction to quantum communication: qubit generation and propagation. **List of Experiments:** 1. Michelson interferometer experiment 2. CCD Spectrometer experiment 3. Pockels effect experiment 4. Optical fiber experiment 5. He-Ne laser cavity experiment 6. Kerr effect experiment 7. Mach-Zehnder interferometer experiment 8. External cavity diode laser: assembly and characteristics 9. Haidinger fringes for measuring thickness of the film 10. Diffraction using gratings 11. Polarization of light 12. Generation of orbital angular momentum of light 13. Recording and reconstruction of hologram 14. Demonstration of Faraday rotation principle
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3

Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, 1991. • R. S. Longhurst, Geometrical and Physical Optics, Longman, 1967. • W. T. Silvfast, Laser Fundamentals, Cambridge University Press, 2008. • W. Demtroder, Laser Spectroscopy, Vol. 1, Basic Principles, 4^{th} Edition, Springer, 2008. • 5. Robert W. Boyd, Nonlinear Optics, 2^{nd} Edition, Academic Press, 2003.
References:	• Laboratory Manual and References therein

Course Number	**PH4204**
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Introduction to Nuclear and Particle Physics
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	This is an introductory course of Nuclear and Particle Physics. The course covers tools (accelerators, detectors), nuclear properties, nuclear forces, nuclear models, radioactive decay and nuclear reactions. Fundamentals of particle interactions and forces, symmetries and conservation laws, basics of electroweak theory of the Standard Model and origin of mass etc. will be discussed. Topics will be taught with key experiments.
Course Outline	Nuclear properties: mass, radius, spin, parity, binding energy, electric and magnetic moments, excited states; Nuclear models: liquid drop model, semi-empirical mass formula, nuclear shell model - validity and limitations, magic numbers, Collective models; Deuteron problem.; Nature of the nuclear force: form of nucleon-nucleon potential, charge-independence and charge-symmetry of nuclear forces; Radioactive decay: radioactive decay law, production and decay of radioactivity, radioactive dating, elementary ideas of alpha, beta and gamma decays and their selection rules; Nuclear reactions: reaction mechanism, Fission and fusion, compound nuclei and direct reactions, elementary ideas about nuclear reactors. Particle Phenomenology: Fundamental interactions; Elementary particles and their quantum numbers (charge, lepton number, baryon number, spin, parity, isospin, strangeness, etc.); Gellmann-Nishijima formula, Quark model, baryons and mesons; C, P, and T invariance, Symmetries and conservation laws - application of symmetry arguments to particle reactions; Parity non conservation in weak interaction; Elementary idea about electroweak unification, Higgs boson and origin of mass; Elementary introduction to accelerators; Relativistic kinematics.
Learning Outcome	Complies with PLO 1, 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• D. Griffiths, Introduction to Elementary Particles, Wiley, 2008. • Kenneth S. Krane, Introductory Nuclear Physics, Wiley, 2008. • A. Das, T. Ferbel, Introduction to Nuclear and Particle Physics, World Scientific, 2003. • S.N. Ghoshal, Nuclear Physics, S Chand, 1994.
References:	• Martin B. and Shaw G. P., Particle Physics, Wiley. • Detectors for Particle Radiation, Konrad Kleinknecht, Cambridge. • Techniques for Nuclear and Particle Physics Experiments: A How-To Approach, William R. Leo, Springer. • Roy R. and Nigam B. P., *Nuclear Physics: Theory and Experiment,* New Age. • J. Lilley, Nuclear Physics, Wiley, 2006. • Hughes I. S., *Elementary Particles*, Cambridge. • D. H. Perkins, Introduction to High Energy Physics, 4th edition, Cambridge, 2000. • Halzen F. and Martin Alan D., Quarks and Leptons, Wiley India edition. • Mittal V. K., Verma R. C., Gupta S.C., *Introduction To Nuclear And Particle Physics,* Prentice-Hall of India Pvt. Ltd.

Sl. No.	Subject Code	Departmental Elective – I	L	T	P	C
1.	PH4205	Quantum Mechanics-II	2	1	0	3
2.	PH4206	Thin Film Technology	3	0	0	3
3.	PH4207	Introduction to Medical Physics	2	1	0	3
4.	PH4208	Introduction to Data Science for Physicists	2	1	0	3

Course Number	**PH4205**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Quantum Mechanics-II
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	In this course students will learn time dependent perturbation theory, scattering theory and relativistic quantum mechanics.
Course Content	Time dependent perturbation theory, Schrödinger, Heisenberg and interaction pictures.; Constant and harmonic perturbations Fermi's Golden rule; Scattering theory: Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Born approximation, Greens functions, scattering for different kinds of potentials; Partial wave analysis; Special topics in radiation theory: semi-classical treatment of interaction of radiation with matter Symmetries in quantum mechanics: Conservation laws and degeneracy associated with symmetries; Continuous symmetries, space and time translations, rotations; Rotation group, Wigner-Eckart theorem; Discrete symmetries; parity and time reversal. Relativistic quantum mechanics, Klein-Gordon equation, Interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space, spinors; Spin and magnetic moment of the electron.
Learning Outcome	Complies with PLO 1, 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Quantum Mechanics (Vol-II), C. Cohen-Tannoudji, John Wiley & Sons, Asia, 2005. • Advanced Quantum Mechanics, J. J. Sakurai, Pearson Education, 2007. • Principles of Quantum Mechanics, R. Shankar, Springer, India, 2008.
References:	• Quantum Mechanics, L. I. Schiff, McGraw-Hill, 1968. • Quantum Mechanics, E. Merzbacher, John Wiley, Asia, 1999. • Quantum Mechanics, V.K. Thankappan, Wiley Eastern, 1985. • The Feynman Lectures on Physics, Vol.3, R.P. Feynman, R.B. Leighton and M.Sands, Narosa Pub. House, 1992. • The Principles of Quantum Mechanics, P.A.M. Dirac, Oxford Univ. Press, 1991. • Quantum Mechanics-Nonrelativistic Theory, L.D.Landau and E.M. Lifshitz, 3rd Edition, Pergamon, 1981. • Quantum Mechanics, B. H. Bransden and C. J. Joachain, Pearson Education 2nd Ed., 2004.

Course Number	**PH4206**
Course Credit L–T–P–C:	3-0-0-3
Course Title	Thin Film Technology
Learning Mode	Classroom Lectures
Learning Objectives	The science of technology involved behind growth, characterization and uses of Thin Film of various materials.
Course Description	Module-1 deals introduces to thin film and its importance. The physical processes behind growth of thin film is also discusses. Module-2 deals with the knowledge of vacuum technology which is relevant for growth of thin film. Module-3 discusses about various techniques for growth of thin film which makes use of vacuum technology also. Module-4 deals with various characterization methods of thin films, and lastly discusses about applications.
Course Outline	**Module-1:** Motivation; Structure, defects, thermodynamics of materials, mechanical kinetics and nucleation; grain growth and thin film morphology; **Module-2:** Basics of Vacuum Science and Technology, Kinetic theory of gases; gas transport and pumping; vacuum pumps and systems; vacuum gauges; oil free pumping; aspects of chamber design from thin film growth perspectives; **Module-3:** Various Thin film growth techniques with examples and limitations; Spin and dip coating; Langmuir Blodgett technique; Metal organic chemical vapor deposition; Electron Beam Deposition; Pulsed Laser deposition; DC, RF and Reactive Sputtering; Molecular beam epitaxy; **Module-4:** Characterization of Thin films and surfaces; Thin Film processing from Devices and other applications perspective.
Learning Outcome	Complies with PLO 1a
Assessment Method	Quiz, Seminar, Mid-semsester examination, End-semester examination
Suggested Readings:	• Materials Science of Thin Films Deposition and Structure, Milton Ohring. • Thin Film Solar Cells, Chopra and Das. • Thin Film Deposition: Principles and Practice, Donald Smith. • Handbook of Thin Film Deposition (Materials and Processing Technology), Krishna Seshan • Handbook of Physical Vapor Deposition, D. M. Mattox

Course Number	**PH4207**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Introduction to Medical Physics
Learning Mode	Lectures
Learning Objectives	The objectives of the course are to learn the mechanism and functions of different senses of the human body and, to understand the physics formulation of the human body. Also to understand the different equipment used for imaging the human body and, how it helps the medical practitioner.
Course Description	The course discusses breathing and the metabolism of the human body. Biomechanics and fluid dynamics of the circulatory system are discussed elaborately. The functions of ultrasound, X-ray, MRI, etc. is elaborately taught. Radiation physics and its use in medical science for cancer treatment is discussed.
Course Content	**Breathing and Metabolism:** Breathing, Human Elevation limits, Oxygen transfer in the brain, Photo synthesis, Oxygen transfer in the body, Network theory of the human breathing apparatus, Transport phenomena at the cell membrane, Dielectric measurement of exocytosis processes, Diffusion and scale qualities. **Biomechanics and fluid dynamics of the circulatory system:** Bone structures, Ski binding, Elasticity of the vertebrae, lifting a patient, Bones of uniform strength, lifting weights, the blood as a power fluid, Branching, Bypass, Flow coefficients, Narrowing of the aorta, Blood pressure in the aorta, pulsatile blood flow. **The Senses, Electric currents, Fields and Potential:** Information processing, Glasses, Optical illusions, Retina implantation, threshold of vision of the human eye, Visual angle and resolution, Sound propagation, Threshold of hearing, Nerve stimulation, Electrical model of a cell membrane, Measurement of cell membrane potentials. **The physics of Diagnostics and Therapy:** X-ray diagnostics and Computed tomography, Ultrasound, Nuclear magnetic resonance, Magnetic Resonance Imaging, Nuclear diagnostics and positron emission tomography, Temperature measurement system, Blood Pressure measurement, ECG, ECHO; PCR and CT. **Radiation medicine and protection:** Pair production in radiation therapy, Compton scattering, Radiation damage from potassium, Lethal energy dose, Fatal does equivalents, Laser therapy.
Learning Outcome	Complies with PLO 2b
Assessment Method	Assignments, Mini projects, Quizzes, Mid-semester examination, End-semester examination.
Suggested Readings:	
Textbooks:	• Medical Physics, W. A. Worthoff, H. G. Krojanski, D. Suter, De Druyter, 2014. • Medical Physics and Biomedical Engineering, B. H. Brown, R. H. Smallwood, D. C. Barber, P. V. Lawford and D. R. house, Taylor & Francis, New York, 1999.
References:	• The Essential Physics of Medical Imaging, Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt, Jr., and John M. Boone, Wolters Kluwer | Lippincott, Williams & Wilkins, 2011. 3rd Edition, Philadelphia. • Medical Physics, Martin Hollins, Nelson Thornes Ltd. 2001. • The Physics of Radiology, H. E. Jones, J. R. Cunningham, Charles C. Thomas, New York, 2002. • Radiation Oncology Physics: A Handbook for Teachers and Students, E.B. Podgorsak, IAEA Publ., 2005.

	• Handbook of Bio-Medical Engineering, Jacob Kline, Academic Press Inc., Sandiego, Oxford University Press, 2004. • Smart Biosensor Technology, G. K. Knoff, A. S. Bassi, CRC Press, 2006. • Physics of Diagnostic Radiology, Thomas S Curry, IV Edition, Lippincott Williams & Wilkins, 1990. • The Essential Physics for Medical Imaging, Jerrold T Bushberg, J. Anthony Seibert, Edwin M. Leidholdt Jr., John M. Boome, Lippincott Williams & Wilkins, 2nd Edition, 2012. • Medical Physics: Imaging, Jean A. Pope, Heinemann Publishers, 2012. • Nanobiotechnology: Concepts, Applications and Perspectives, Niemeyor, Christober M. Mirkin, Kluwer publications, USA, 2004. • Physical Principles of Medical Ultrasonics, C. R. Hill, J. C. Bamber, G. R. ter Haar, John Wiley & Sons, 2005. • Diagnostic Ultrasonic Principles and Use of Instrument, W. M. McDicken, 2nd Edition, John Wiley & Sons, New York, 1992.

Course Number	**PH4208**
Course credit (L-T-P-C)	2-1-0-3
Course title	Introduction to Data Science for Physicists
Learning mode	Offline
Learning objectives	• An introduction to data science career path for physicists. • Understanding the basics of machine learning and ML model building. • Exposition to popular python-based environments like Jupyter, Kaggle which are used industry-wide for AI/ML or data science applications. • Using state-of-the-art libraries like pandas and sklearn to preprocess the data, apply ML models, validate, and test predictions. • Hands-on experience through real-world projects.
Course description	Data science is increasingly becoming an essential skill for physicists. While there are numerous courses and programs on data science offered across various media, these are almost invariably targeted at computer science graduates and industry professionals. This course is designed to bridge this gap by introducing essential data science techniques from the perspective of applications in physics research and prepare learners for advanced courses in ML/AI/Data science.
Course content	Python and programming environments: review of python, setting up local python development environment, setting up Jupyter, introduction to Kaggle-cloud based python notebook and data science platform, creating first python program on Kaggle/Jupyter notebook, basics of numpy library, file versioning using github. The what and why of machine learning, mathematical basis of ML – setting up a problem, example of linear and polynomial regression; statistical learning theory – bias, variance, model complexity; cost function, gradient descent, basics of supervised and unsupervised learning, regression with multiple variables, feature normalization, basics of neural networks, building first ML model – handling data for training, testing, and validation, types of models, using scikit-learn library, ML pipelines; data science techniques – pandas, data cleaning, data visualization. Hands-on project – detection of gravitational waves – introduction to gravitational waves, Fourier transform, noise, GW signal analysis, data fitting. Hands-on project – Detection of signal and background events at the LHC and other colliders.
Pre-requisites	• Linear algebra, matrices, vector algebra • Basic familiarity with programming in Python
Learning outcomes	Upon successful completion of this course, students will be able to: • write intermediate-level programs in Python, define functions, import and use libraries. • Work on projects in Jupyter environment, and collaborate on group projects on platforms like Kaggle, and github. • Understand the fundamental concepts of machine learning and theoretical understanding of how ML models are developed. • Understand and manipulate data for training, validating, and testing predictions of ML models. • Use various python libraries like scikit-learn, pandas, numpy, etc. to create ML pipelines that take in given data and generate predictions. • Get exposure to real-world usage of data science techniques in trending research areas.
Assessment method	Project, Assignments, Quiz, Mid-semster examination, End-semester examination
Suggested Readings:	

Textbooks:	• Christopher Bishop, Pattern Recognition and Machine Learning, Springer, 2007 • Introduction to Machine Learning Edition 2, by Ethem Alpaydin • Machine Learning. Tom Mitchell. First Edition, McGraw- Hill, 1997.
References:	• A high-bias, low-variance introduction to Machine Learning for physicists, Pankaj Mehta, Marin Bukov, Ching-Hao Wang, Alexandre G.R. Day, Clint Richardson, Charles K. Fisher, David J. Schwab, 2019, Phys. Rep. 810, 1. • John Hopcroft, Ravindran Kannan, Foundations of Data Science, 2014. • I. Goodfellow, Y. Bengio, A. Courville. Deep Learning. MIT Press, 2016. • Machine learning & artificial intelligence in the quantum domain, Vedran Dunjko, Hans J. Briegel, arXiv:1709.02779 • Andrew Ng's lectures on machine learning, Coursera, https://www.coursera.org/learn/machine-learning-course/

Sl. No.	Subject Code	Course Name	L	T	P	C
1.	PH5101	Atomic and Molecular Physics	3	1	0	4
2.	PH5102	Condensed Matter Physics-I	3	0	0	3
3.	PH5103	Atomic, Molecular and Nuclear Physics Laboratory	0	0	4	2
4.	PH51XX	Department Elective - II	X	X	X	3*
5.	XX61PQ	Inter-Disciplinary Elective - I	3	0	0	3*
6.	PH5199	Project - I	0	0	12	6
		Total				**21**

Course Number	**PH5101**
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Atomic and Molecular Physics
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course provides students building strong fundamentals in Atomic Physics and Molecular physics. Also this course introduces methods and models which are very essential to pursue research in advanced theoretical and experimental physics.
Course Outline	Interaction of one electron atoms with electromagnetic radiation, Transition rates, The dipole approximation, Selection rules, Spectrum of one electron atoms, Line intensities and the life time of the excited states, Line shapes and widths, Fine structure and Hyperfine structure, The Lamb Shift, Zeeman and Stark effect. Many electron atoms: L-S coupling and j-j coupling, Central field approximation, Thomas Fermi model, Hartree- Fock method and the SCF, Interaction of many electron atoms with electromagnetic radiation. Molecular structure, Born -Oppenheimer approximation, Electronic structure of diatomic molecule, Electronic, Rotational, Vibrational and Vibration-Rotation Spectra of diatomic molecules, Electronic spectra of diatomic molecules, The Franck-Condon principle. Introduction to the Density functional theory
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• B.H. Bransden and C.J. Joachain, Physics of Atoms and Molecules, Longman Scientific and Technical, 1983. • Gordon W and F. Drake, Springer Handbook of Atomic, Molecular, and Optical Physics, Springer, 2006. • W. Demtroder, Atoms, Molecules and Photons, Springer, 2010. • H. Haken and H.C. Wolf, Physics of Atoms and Quanta, Springer, 2005. • H. E. White, Introduction to Atomic Spectra, McGraw Hill, 2019 • G. K. Woodgate, Elementary Atomic Structure, 2nd Ed., Clerenton Press, Oxford, 2002 • M. Karplus and R. N. Porter, Atoms and Molecules: An Introduction for Students of Physical Chemistry
References:	• Ira N. Levine, Quantum Chemistry, 6th Edition, PHI Learning Private Limited, New Delhi, 2009. • John P. Lowe and Kirk A. Peterson, Quantum Chemistry, 3rd Edition, Academic Press, 2009. • Peter Atkins and Ronald Friedman, 4thEdition, Oxford Univ. Press, 2012. • Collin N. Banwell and Elain M. Mc Cash, Fundamentals of Molecular Spectroscopy, 4thEdition, Tata McGraw Hills, 2008.

Course Number	**PH5102**
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Condensed Matter Physics – I
Learning Mode	Lectures & Tutorials
Learning Objectives	To explore a variety of phenomena associated with the major forms of solid matter, while laying the foundation for a working understanding of solids through clear, detailed, and elementary treatments of fundamental theoretical concepts.
Course Description	This course deals with basic theory of solids which are important to understand the vast range of real solids, with an emphasis on its structure and physical properties. This includes topics that are entirely based on classical methods, and also those which demand a detailed quantum treatment. The concepts of statistical mechanics, thermodynamics and mathematical methods are inherently present in this course due to its interdisciplinary approach. The course includes theories of metals, insulators, and semiconductors. Electrical, mechanical, thermal, magnetic and superconducting properties are discussed with detailed analysis.
Course Outline	**Crystal physics:** Symmetry operations; Bravais lattices; Point and space groups; Miller indices and reciprocal lattice, Brillouin zones; Structure determination; diffraction; X-ray; Crystal binding; Defects in crystals; Point and line defects. **Lattice vibration and thermal properties:** Normal modes of crystal vibrations, Phonon, Einstein and Debye models for specific heat of crystals; acoustic and optical modes of linear lattice; thermal conductivity of metals and insulators and its variation with temperature. **Electronic properties:** Drude model and Free electron theory of metals; electrons in a periodic potential; Bloch theorem; Kronig-Penny model; band theory-nearly free electron and tight binding model; Semiconductor physics; Semi-classical theory of transport; Quantum Hall effect. **Magnetic properties:** Para, Ferro and Dia magnetism, Pauli para magnetism, Landau dia magnetism, Phase transition, Hund's rule and quenching **Superconductivity:** General properties of superconductors, Meissner effect; London equations; Flux quantization, coherence length; type-I and type-II superconductors, Cooper pairs
Learning Outcome	Complies with PLO 1a, 1b, 3
Assessment Method	Tutorials, Assignments, Mid-semester exam, End-semester exam
Suggested Readings:	
Textbooks:	• C. Kittel, Introduction to Solid State Physics, Wiley, India, 2009. • M. A. Omar, Elementary Solid State Physics, Addison-Wesley, 2009.
References:	• A. J. Dekker, Solid State Physics, Macmillan (2009). • N. W. Ashcroft and N. D. Mermin, Solid State Physics, HBC Publ., 1976. • H. P. Myers, Introduction to Solid State Physics, Taylor & Francis, 1997. • Richard Zallen, The Physics of Amorphous Solids, John Wiley and Sons Inc., 1983.

Course Number	PH5103
Course Credit (L-T-P-C)	0-0-4-2
Course Title	Atomic, Molecular and Nuclear Physics Laboratory
Learning Mode	Laboratory
Learning Objective	To develop experimental skills for setting up the experiments and perform them
Course description	In this lab course, the students need to perform several experiments related to atomic molecular and nuclear physics.
Course outline	List of Experiments: 1. Bohr Magneton by Zeeman Effect Experiment 2. Absorption coefficient of gamma-rays in Aluminium 3. Low and high counting statistics using G. M. Counter 4. Gamma-ray spectrometry using NaI(Tl) scintillator 5. Compton scattering of gamma-ray using 137Cs source 6. Coincident study of annihilation photons using 22Na source 7. Rutherford scattering of alpha particles in gold 8. UV visible spectrophotometer 9. Fluorimeter 10. IR spectrometer 11. Raman spectrometer 12. FTIR 13. Sodium spectrum (D1, D2 line) 14. Stark effect 15. Saturation Absorption Spectroscopy: Observation of Hyperfine Splitting [About 8-10 experiments out of the above list will be offered in a semester]
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a),2(b) and 3
Assessment Method	LaboratoryReports, Viva-voce and end-sem exam
Suggested Reading	LaboratoryManual and references therein

Sl. No.	Subject Code	Departmental Elective - II	L	T	P	C
1.	PH5104	Electrodynamics-II	3	0	0	3
2.	PH5105	Nano photonics	2	1	0	3
3.	PH5106	Nanoscience	2	1	0	3
4.	PH5107	Quantum Theory of Collisions	2	1	0	3
5.	PH5108	Introductory Biophysics	2	1	0	3
6.	PH5109	Spintronics	2	1	0	3
7.	PH5110	Magnetism at Nanoscale	2	1	0	3
8.	PH5111	Mathematical Physics-II	2	1	0	3
9.	PH5112 /PH5208	Introduction to Nonlinear Dynamics and Chaos	3	0	0	3
10.	PH5113 /PH5219	Quantum Field Theory	2	1	0	3
11.	PH5114	Physics of Ultra cold Atoms	2	1	0	3

Course Number	**PH5104**
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Electrodynamics-II
Learning Mode	Lectures & Tutorials
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course introduces students to advanced Electrodynamics focusing on EM radiation, Scattering of EM waves and relativistic Electrodynamics. These topics will help students to understand advanced applications in EM theory as well as to build a strong platform towards advanced research topics in this area.
Course Outline	**Radiation:** Radiation from an oscillating electric dipole and magnetic dipole; Radiation from an arbitrary source. Retarded potential, Jefimenko's equation, Lienard-Wiechart potentials, Potentials and fields due to a point charge moving with constant velocity; fields due to an accelerated point charge in arbitrary motion, Larmor's formula and its relativistic generalization; Radiation for co-linear motion (velocity and acceleration are parallel) – Bremsstrahlung; Radiation when velocity and acceleration are perpendicular – SynchotronRadiation; Cherenkov Radiation (qualitative only). Radiation reaction, Abraham-Lorentz formula and it's problem, Physical basis and mechanism responsible for radiation reaction. Limitations of classical electrodynamics. Antennas and arrays; Detection of radiation. **Scattering of EM waves**: Scattering of radiation by a free charge - Thomson's scattering; Scattering of radiation by a bound charge – Rayleigh scattering, Compton scattering. **Relativistic Electrodynamics:** Lorentz Transformation (LT) and inverse LT in tensor notation. Electromagnetic field tensor ($F\mu\nu$). Covariant formalism of Maxwell's equations using $F\mu\nu$. Lorentz Transformation of electromagnetic fields. Fields due to a point charge in uniform motion - Lienard-Wiechart fields from LT. Relativistic Lagrangian formulation of the motion of charged particle in an electromagnetic field.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a),2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Introduction to Electrodynamics, D J. Griffiths, Pearson Education, 2006. • Electromagnetics, B. B. Laud, New Age International (P) Limited, 1987. • Classical Electrodynamics, J. D. Jackson; Willey, 1999.
References:	• (i) Electrodynamics of Continuous Media & (ii) Classical theory of fields - L.D. Landau and E.M. Lifshitz; Butterworth-Heinemann 1984 & 1987. • Classical Electrodynamics - Walter Greiner, D. Allan Bromley, Sven Soff; Springer, 1998. • The Feynman Lectures on Physics: Vol II - R. P. Feynman; Pearson .Education India (2012) • Foundations of Electromagnetic Theory - J.R. Reitz, F.J. Milford & R. W. Christy; Narosa, 1979. • Principles of Electrodynamics - Melvin Schwartz; Dover, 2003.

Course Number	**PH5105**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Nanophotonics
Learning Mode	Lectures
Learning Objectives	This course is designed to provide specialized knowledge related to an advanced field of optics and photonics.
Course Description	This course covers (i) various fundamental and advanced concepts related to light-matter interactions at the nanoscale and (ii) the theory and fabrication details of nanoscale photonic devices for several applications.
Course Outline	Foundations of nanophotonics, Near-field interaction and microscopy, Quantum confined materials, Sub-wavelength phenomena and plasmonic excitations (plasmonic wave guiding), Nano control of excitation dynamics (nanostructure and excited states), Photonic crystals (theoretical modeling, features, methods of fabrication, photonic crystal sensors, photonic crystal fibers), Meta-materials, Nanophotonics for Biotechnology & Biomedicine.
Learning Outcome	Complies with PLO (2)
Assessment Method	Assignments, Quizzes, Mid-semester examination, and End-semester examination
Suggested Readings:	
Textbooks/References:	• Paras N. Prasad, Nanophotonics, John-Wiley-Interscience, 2004. • Sergey V. Gaponenko, Introduction to Nanophotonics, Cambridge University Press, 2010. • Hiroshi Masuhara and Satoshi Kawata, Nanophotonics; Integrating Photochemistry, Optics and Nano/Bio Materials Studies, Elsevier, 2004. • Mark L. Brongersma and Pieter G. Kik, Eds., Surface Plasmon Nanophotonics, Springer, 2007. • MotoichiOhtsu, Ed., Progress in Nanophotonics, Springer, 2011.

Course Number	**PH5106**
Course Credit L–T–P–C	2-1-0-3
Course Title	Nanoscience
Learning Mode	Lectures
Learning Objectives	The objective of the course is developing basic understanding, type, synthesis about Nanoparticle. The wonderful game of physics playing behind bizarre physical properties of Nanoparticles is also dealt.
Course Description	The course first provides the fundamental physics knowledge that is required for the understanding of Nanoparticles, especially its physical properties. These are dealt in Module-1 and Module-2. In Module-3, the approach to synthesis of Nanoparticles is dealt. Module-4 deals with various types of Nanoparticles and it properties. Lastly, Module-5 discusses about various spin-off field of research related to Nanoparticles.
Course Outline	**Module-1:** Background to Nanoscience, length scales and size effects in smaller systems-pre quantum, review of quantum and statistical mechanics, quantum wells, quantum wires and quantum dots, band structure and density of states, inter band transitions; **Module-2:** Electrical transport in nanostructures – Quantum confinement, Coulomb blockade and Conductance quantization, conduction mechanisms -Thermionic effect, Schottky and Poole-Frenkel effect, Arrhenius type thermally activated conduction, variable range hopping conduction and Polaron conduction; **Module-3:** Synthesis –Top, –down, and bottom-up approach, characterization of nanostructures; Module 4: Semiconductor quantum dots, self-assembled monolayers, Metal nanoparticles, core-shell nanoparticles, nano-shells, new nanostructures -carbon (fullerenes, CNTs, graphene, nanodiamond), BN nanotubes; Nanotribology and Nanorheology, stiction, van der Waal's and Casimir forces; **Module-5:** Applications in Nanobiology, Nano sensors, Nanoelectronics, Nanomedicines, Molecular nanomachines.
Learning Outcome	Complies with PLO 1a 2a 2b
Assessment Method	Mid Semsester (40%) Exam and End Semester (60%) Exam
Suggested Readings:	• Nano – The Essentials, by T. Pradeep, McGraw-Hill Education, 2014. • Introduction to Nanoscience, G. L. Hornyak, J. Dutta, H. F. Tibbals, A. Rao, CRC Press, 2008. • Introduction to Nanoscience and Technology, K. K.Chattopadhyay, A. N. Banerjee, PHI Learning Private Ltd., 2009. • Introductory Nanoscience, Masuro Kuno, Garland Science, 2011. • Introduction to Nanotechnology, Poole and Owen, Wiley Indian Edition, 2010. • Nanophysics and Nanotechnology, Edward L. Wolf, Wiley-VCH, 2006. • Nanotechnology, Lynn E. Foster, Pearson, 2011. • Quantum Mechanics, J. J. Sakurai. • Statistical Mechanics,Kerson Huang. • Fundamentals and Applications of Nanomaterials, Z. Guo and Li Tan. • Nanoelectronics and Information technology, Rainer Waser, Wiley-VCH, 2005.

Course Number	**PH5107**
Course Credit	2-1-0-3
Course Title	Quantum Theory of Collisions
Learning Mode	Lectures
Learning Objectives	Complied with Program Goal 1, 2, 3
Course Description	The course aims at an advanced level understanding of collision physics. The course starts with elastic scattering of non-Coulombic potentials and the deals with Coulomb scattering. It further deals with resonant scattering and gives an introduction to Feynman diagrams.
Course Outline	Quantum collisions: Optical theorem, Method of Partial wave, Phase shift analysis, Resonances, Integral equation of potential scattering; Lippman-Schwinger equation, Coulomb scattering. Occupation number representation: creation, destruction and number operators, Many-particle Hamiltonian in occupation number representation, The Hartree-Fock method and the free electron gas, Exchange, statistical and Fermi-Dirac correlations, Time dependence and Dirac picture of quantum mechanics, Dyson's perturbation expansion for the evolution operator. Feynman Graphs: Creation and destruction operator in the interaction picture, First order Feynman diagrams, Second and higher order Feynman diagrams. Resonances in Quantum scattering: Scattering of partial wave, Resonances in quantum collisions, Breit-Wigner formalism, Fano parameterization of Breit-Wigner formula, Resonance life time, Time delay in scattering and photoionization.
Learning Outcome	Complies with PLO 1a, 1b, 2a, and 3
Assessment Method	Assignment, Quiz, Mid-semester and End-semester examination
Suggested Readings:	
Textbooks:	• Quantum Collision Theory, C. J. Joachain, Elsevier, 1984. • Many-electron Theory, S. Raimes, North-Holland Publishing Company, 1972. • Quantum Theory of Many-Particle Systems, A. L. Fetter and J. D. Walecka, Dover Books (2003).
References	• Atomic Collisions and Spectra, U. Fano and A. R. P. Rau, Academic Press, 1986. • Relativistic Quantum Theory of Atoms and Molecules, I. P. Grant, Springer, 2007. • Quantum Theory of Scattering, T. Wu and T. Ohumura, Prentice Hall, 1962. • Atomic Structure Theory, W. R. Johnson, Springer, 2007.

Course Number	**PH5108**
Course Credit(L-T-P-C)	2-1-0-3
Course Title	Introductory Biophysics
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2a and 3
Course Description	Students will be equipped with thermodynamics at a molecular level, with structure function relation of bio-macromolecules like DNA, RNA, Protein and membranes. The importance of molecular recognition and experimental methods for their determination.
Course Content	Review of basic concepts in thermodynamics and statistical mechanics: Entropy, Free energy, Random walk-in biology, Introduction to force, time and energy at mesoscopic scales. Hydrophobicity, Ficks law of diffusion, Rigidity and elasticity. Bio-macromolecules: Nucleic acid structure and properties, Protein structure, Ramachandran plot, Protein folding problem, Levinthal Paradox, enzyme kinetics, Membrane structure and Ion channels, Central Dogma, Gene Expression, Genetic code. Molecular Recognition: Thermodynamics of Binding, Allostery and Cooperatively, Specificity of macromolecular recognition, Protein-Nucleic acid Interaction, Protein-Protein Interaction. Experimental methods for structure-function relation in biopolymers: Transient absorption and fluorescence, FRET, FCS, Forced spectroscopic technique (optical tweezers, AFM and Magnetic trap).
Learning Outcome	Complies with PLO 1a, 2 and 3
Assessment Method	Assignments, Quiz, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Biophysical Chemistry; Cantor and Schimmel I, II and III. ISBN-13: 978-0716711902, ISBN-13: 978-0716711889 and ISBN-13: 978-0716711926. • The Physics of Living process; A Mesoscopic Approach. T. A. WaighISBN: 978-1-118-44994-3. • Molecular Biophysics, Structure in Motion. M. Daune. ISBN-13**:** 978-0198577829.
References:	• Molecular Driving Forces; Statistical Thermodynamics in Biology, Chemistry, Physics and Nanoscience. Ken A Dill and Sarina Bromberg. ISBN- 0815320515. • The Molecules of Life: Physical and Chemical Principles, John Kuriyan, BoyanaKonford, and David Wemmer, Garland Science. • Random Walks in Biology, Howard C. Berg, Princeton Univ. Press.

Course Number	**PH5109**
Course Credit	2-1-0-3
Course Title	Spintronics
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	The course starts with the basics of quantum spin and magnetism, thereafter developing on advanced topics in spin-based electronics, different phenomenon, device design, control and applications. It covers areas of modern-day technological developments in this area with advanced materials engineering.
Course Outline	Background and overview of spin electronics: Classes of magnetic materials; The early history of spin (Bohr model, quantization, Stern-Gerlach experiment); Quantum Mechanics of spin; The Bloch sphere; Spin-orbit interaction (ex: Rashba, Dresselhaus interaction) Exchange interaction; Spin Hamiltonians; Spin relaxation mechanisms; spin relaxation in a quantum dots; The spin Galvanic effect; Spin diffusion and lifetime; Hanle Effect; Basic electron transport; Spin-dependent transport; Spin dependent tunnelling; Magnetoresistance, GMR, TMR, Spin-Valve and exchange-bias, Andreev Reflection at ferromagnet and Superconductor interfaces Spin-transfer torques; Spin-transfer drive magnetic dynamics; Current-driven switching of magnetization and domain wall motion; Domain wall scattering and Current-Induced switching in ferromagnetic wires Spin injection; spin accumulation and spin current; Spin hall effect; Silicon based spin electronic devices; Spin transistors and Datta-Das transistor; Materials for spin electronics; Heusler alloy and half-metals Spintronics technology: Read Heads; MRAM; Field Sensors; Spintronic Biosensors; Quantum Computing with spins; 2D material based spintronics; Topological spintronics; superconducting spintronics
Learning Outcome	Complies with PLO 1(a),1(b), 2(a) and 3a
Assessment Method	Quiz, Assignments, Mid-semester and End-semester examination
Suggested Readings:	
Textbooks:	• S. Bandyopadhyay, M. Cahay, Introduction to Spintronics, CRC Press, 2008. • Nanomagnetism and Spintronics, Ed., Teruya Shinjo, Elsevier, 2009 • Concepts in Spin Electronics, Ed., S. Maekawa, Oxford Science Publications, Oxford Univ. Press.
References:	• Handbook of Spintronics, Ed., Y. Xu, David Awschalom, J. Nitta, Springer, 2015 • Y.B. Xu and S. M. Thompson, Spintronic Materials and Technology, Taylor & Francis, 2006. • Magnetism in Condensed Matter Physics by Stephen Blundell, Oxford University Press

Course Number	**PH5110**
Course Credit(L-T-P-C)	2-1-0-3
Course Title	Magnetism at Nanoscale
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	Equips the students with the fundaments and applications of magnetism, magnetic materials, measurements and spintronics. It allows them to apply the knowledge in both research and industrial scenarios.
Course Content	Why magnetism at nanoscale ? experimental methods; Magnetic anisotropy at nanoscale; Magnetostriction and the effect of stress; Domains and magnetization process; Fine particle and thin films; soft magnetic materials and hard magnetic materials, One-dimensional Heisenberg model; Two-dimensional XY model; Three-dimensional Heisenberg ferromagnet; Three-dimensional antiferromagnet; Magnetism of the electron gas; Stoner model; Spin excitations in Stoner model; RKKY interaction; Field models of magnetization; Exchange model in two dimensions; Magnetic domains and domain walls; Random anisotropy model of amorphous magnet; Gilbert-Landau-Lifshitz equation; Spin waves; Magnetic resonance; Angular momentum and spin; Magnetism of atoms; Exchange interaction and magnetic anisotropy; Superparamagnetism; Quantum mechanics of a large spin; Quantum magnetization curve; Josephson effect; Spin-lattice relaxation of rigid atomic clusters; Spin transport at nanoscale; Magnetic materials in applications; Magnetoresistive Sensors Based on Magnetic Tunneling Junctions; Magnetoresistive Random Access Memory (MRAM); Emerging Spintronic Memories; GMR Spin-Valve Biosensors; Semiconductor Spin-Lasers; Spin Logic Devices and magnetic drug delivery; Magnetic materials in memory device.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a), 2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Magnetism in Condensed Matter, Stephen Blundell, Oxford University Press. • Introduction to Magnetic Materials, 2nd Edition, L. C. Cullity and C. D. Graham, IEEE Press, Willey. • Handbook of Spin Transport and Materials and Magnetism, Editors – Evgeny Y.Tsymbal and Igor Źutić, CRC Press – Taylor & Francis Group • Magnetism: From Fundamentals to Nanoscale Dynamics [Hardcover] Joachim Stöhr, Hans Christoph Siegmann (Springer-Verlag). • Principles of Nanomagnetism, Guimarães, Alberto P., Springer, 2009.
References:	• Handbook of Spin Transport and Magnetism, Edited by Evgeny Y. Tsymbal, Igor Zutic, Tailor & Francis, 1st Edition. • Advances in Nanoscale Magnetism, Proceedings of the International Conference on Nanoscale Magnetism (ICNM-2007), June 25 -29, Istanbul, Turkey, Series: Springer Proceedings in Physics, Vol. 122. • Lectures on Magnetism, Eugene Chudnovsky and Javier Tejada, Rinton Press, 1st Edition. • Introduction to Magnetism and Magnetic Materials, David Jiles, Chapman & Hall, 1998.

Course Number	**PH5111**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Mathematical Physics-II
Learning Mode	Lectures & Tutorials
Learning Objectives	The purpose of the course is to introduce students to methods of mathematical physics and to develop required mathematical skills to solve problems in quantum mechanics, electrodynamics and other advanced courses in physics.
Course Description	The course offers detailed study on complex analysis, special functions and group theory. Techniques learned in complex analysis will be important to solve many problems involving integrals. Group theory plays an important role in particle physics. Special functions comes handy in the quantum mechanics, electrodynamics and atomic and molecular physics.
Course Outline	Review of Special functions: Hermite, Bessel, Laguerre and Legendre functions (recurrence and orthogonality relations, series expansion). Spherical harmonics. Group Theory: Definition, Subgroups, Classes and Examples, Group representations (regular and product; reducible and irreducible), Characters, Physical applications, Infinite groups; Lie groups and Lie algebra, Generators: Representations of Z2, SU(1,1), , SU(2), SU(3) and SO(3). Integral Equations: Generating functions, Newman series.
Learning Outcome	PLO 1b, 3
Assessment Method	Mid-semester examination, End-semester examination, Quiz & Assignments
Suggested Readings:	
Textbooks:	• George B. Arfken and Hans J. Weber, Mathematical Methods for Physicists, Academic Press Inc., 4th Edition, 1995. • M. Abramowitz and I. A. Stegan, Handbook of Mathematical Functions, Dover Publs., INC., New York, 1965. • M.R. Spiegel: Theory and Problems of Complex Variables.
References:	• E. Kreyszig, Advanced Engineering Mathematics, Wiley India, 8th Edition, 2008. • R.V. Churchill and J.W. Brown: Complex Variables and Applications. • A. Zee: Group Theory in a Nutshell for Physicists, Princeton University Press, 2016.

Course Number	**PH5112 /PH5208**
Course Credit L-T-P-C	3-0-0-3
Course Title	Introduction to nonlinear dynamics and chaos
Learning Mode	Lectures and Tutorials
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course will help the students to understand the concept and method of theory of dynamical system as well as its applications to physics and engineering.
Course Content	Dynamical system, one dimensional flows: Flows on the line, fixed points and stability, linear stability analysis, Potentials, Solving equaton on the computer, flows on the circle, physical examples like oscillator with and without damping, Bifurcations in one dimensional systems and their classification. Two-Dimensional Flows: Linear Systems and classification, limit cycle, Poincare-Bendixson theory, Bifurcations in two dimensions. Chaos: One dimensional map, Stability, Liapunov exponent, fractals, cantor set. Elementary Fluid Dynamics: Navier-Stokes equation, Turbulent flows.
Learning Outcome	Complies with PLO 1, 2 and 3
Assessment Method	Assignments, Quizzes, Presentation, Mid-semester examination and End-semester examination
Suggested Readings:	**Textbooks:** **1.** Nonlinear Dynamics & Chaos, S. H. Strogatz, CRC Press, 2018. **2.** Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers, D. W. Jordan and P. Smith, 4th ed., Oxford, 2007. 3. Fluid Mechanics, P. K. Kundu, I. M. Cohen and R. David, 6th ed., Academic Press, 2015. **References:** 1. Introduction to Dynamics, I. Percival and D. Richards, Cambridge University Press, 1983. 2. Fluid Mechanics, L. D. Landau, E. M. Lifshitz and L. P. Pitaevskii, Course on Theoretical Physics, Vol. 6, 2nd ed., Elsevier, 2010.

Course Number	**PH5113 /PH5219**
Course Credit	2-1-0-3
Course Title	Quantum Field Theory
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This is an introductory course of Quantum Field Theory (QFT), which is the study of systems in which both special relativity and quantum mechanics are relevant. Students will learn basic concepts and techniques of QFT with special emphasis on Quantum Electrodynamics (QED). Students will learn to calculate the cross section for tree level QED Feynman diagrams. This course will help the students to develop the knowledge base necessary to pursue research in elementary particle physics or high energy physics, particle astrophysics, condense matter physics. **Prerequisites for this course: Quantum Mechanics**
Course Outline	Classical Field Theory: Lagrangian formulation; Lorentz invariance; Noether's theorem and conserved currents, Hamiltonian Field Theory. Canonical quantization of free scalar fields: The Klein-Gordon Equation, Quantization of real and complex scalar fields, The Heisenberg Picture, Propagator. Quantization of Dirac fields: Dirac Equation, Clifford Algebras, Dirac Lagrangian and Hamiltonian, Plane Wave Solutions, Bilinear covariants, Trace formulas, Projection operators, Propagators. Interacting fields: Example of interactions, Interaction picture, Dyson's Formula, S-matrix, Wick's theorem, Feynman Diagrams, Feynman Rules. Quantization of EM field and Quantum Electrodynamics: Quantization of EM fields, Photon Propagator, Local gauge invariance leading to QED, Feynman Rules, Example of calculations for Amplitudes, Decay rates, cross-sections for lowest order QED processes, Crossing Symmetry. Brief review of Parity, Charge conjugation and Time reversal on scalar, Dirac and electromagnetic fields.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• An Introduction to Quantum Field Theory -- M. Peskin and F. Schroeder; Westview Press (1995). • A First Book of Quantum Field Theory -- A. Lahiri and P.B. Pal; Narosa Publishing (2002). • Quantum Field Theory -- L. Ryder; Cambridge University Press (1996). • Quantum Field Theory and the Standard Model -- Mathew D. Schwartz, Cambridge Univ. Press, 2013.
References:	• The Quantum Theory of Fields, Vol. I & II – S. Weinberg; Cambridge Univ. Press, 2005. • Field Theory: A Modern Primer -- P. Ramond; Tylor & Francis, 2020. • Introduction to Gauge Field Theory -- D. Bailin & A. Love; CRC Press, 1993. • Relativistic Quantum Fields -- J.D. Bjorken and S.D. Drell; McGraw-Hill, 1965. • Quantum Field Theory -- F. Mandl and G. Shaw; Wiley, 2010. • Quantum Field Theory in a Nutshell -- A. Zee; Princeton Univ. Press 2010. • Quantum Field Theory -- Itzykson and J.B. Zuber, Dover Publs., 2006.

Course Number	**PH5114**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Physics of Ultracold Atoms
Learning Mode	Lectures
Learning Objectives	Complies with 1,2 and 3
Course Description	This course provides student's both theoretical and experimental aspects of emerging ultra-cold atoms physics highlighting BEC and its applications towards modern cutting edge technology in the research area of Quantum Optics.
Course Outline	Introduction to ultracold atoms and Bose-Einstein condensate (BEC), critical temperature Basic Scattering theory; Second quantization, Mean field theory, Gross-Pitaevskii equation; 1D nonlinear Schrödinger equation; weak, strong and higher order interactions; BEC in a trap, trap engineering and condensate density; Bright & dark Solitons, exact solution; Applications & future technologies: BEC optical lattices; Faraday waves, phase transition, BEC in a chip, atomic beam splitter, atom lasers, Negative temperature etc. Alkali metal gases, Introduction to laser cooling, Velocity dependent force, Optical Molasses, Magneto optical trapping (MOT), Limitations of MOT, Different types of trapping, Magnetic and optical trapping, Evaporative cooling techniques in magnetic and optical trap, Applications in quasi-one dimension, Achieving Bose-Einstein Condensates in pure magnetic and optical traps, Hybrid trapping potentials; Various applications in experiments.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a), 2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• C. J. Pethick & H. Smith, Bose-Einstein Condensation in Dilute Gases, Cambridge Univ. Press, Cambridge, 2008. • A. Griffin, D. W. Snoke & S. Stringari, Bose-Einstein Condensation, Cambridge Univ. Press, Cambridge, 1995. • Robert W. Boyd, Nonlinear Optics, 2nd Edition, Academic Press, 2003.
References:	• Scully, M. O., and M. S. Zubairy. Quantum Optics. Cambridge University Press, 1997. • Harold J. Metcalf, Peter van der Straten, Laser Cooling and Trapping, Springer, 1999. • Lambropoulos. P, Petrosyan. D, Fundamentals of Quantum Optics and Quantum Information, Springer 2007. • M. Lewenstein, A. Sanpera, and V. Ahufinger, Ultracold Atoms in Optical Lattices, Oxford University Press, 2012.

Sl. No.	Code	Course Name	L	T	P	C
1.	PH5201	Condensed Matter Physics Lab	0	0	4	2
2.	PH52XX	Department Elective - III	X	X	X	3*
3.	PH52XX	Department Elective - IV	X	X	X	3*
4.	XX62PQ	Inter-Disciplinary Elective II	3	0	0	3
5.	IK5201	Indian Knowledge Systems	2	0	0	2
2.	PH5299	Project II	0	0	16	8
		Total				**21**

Course Number	PH5201
Course Credit (L-T-P-C)	0-0-4-2
Course Title	Condensed Matter Physics Laboratory
Learning Mode	Laboratory
Learning Objective	To develop experimental skills for setting up the experiments and perform them
Course description	In this lab course, the students need to perform several experiments related to atomic molecular and nuclear physics.
Course Outline	**List of Experiments**: 1. Nuclear *g* factor of a nucleon by NMR spectrometer 2. Susceptibility of a Liquid or a Solution by Quinck's Method 3. Dielectric Constant at different temperature and Curie Temperature of Ferroeledatactric Ceramics 4. Hysteresis Loop for a ferromagnetic sample 5. Lande's g-factor in a free radical using an electron spin resonance spectrometer 6. Energy gap of a semiconductor using four-probe method 7. Measurement of wave length of microwave source 8. Magnetoresistance 9. Thermopower measurement 10. Temperature variation of AC susceptibility using lockin based technique 11. Measurement of thermal conductivity 12. Demonstration of zero resistivity and Meissner effect for a superconductor 13. Gas sensing study of n-MOS/p-MOS 14. Contact resistance measurement using TLM structure / three probe method [About 8-10 experiments out of the above list will be offered in a semester]
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a),2(b) and 3
Assessment Method	LaboratoryReports, Viva-voce and End-semester examination
Suggested Reading	LaboratoryManual and references therein

Sl. No.	Subject Code	Departmental Elective – III	L	T	P	C
1.	PH5202	General Relativity and Cosmology	2	1	0	3
2.	PH5203	Nanoelectronics	2	1	0	3
3.	PH5204	Measurement Techniques	2	0	2	3
4.	PH5205	Quantum Optics & Quantum Information	2	1	0	3
5.	PH5206	Quantum Transport in Mesoscopic Systems	2	1	0	3
6.	PH5207	Condensed Matter Physics-II	3	0	0	3
7.	PH5208 /PH5112	Introduction to Nonlinear Dynamics and Chaos	3	0	0	3
8.	PH5209	Ultrafast Optics and Spectroscopy	2	1	0	3
9.	PH5210	Magnetism: Fundamentals to Application	2	1	0	3
10.	PH5211	Ferroic Phenomena	2	1	0	3
11.	PH5212	Materials for Engineering Applications	2	1	0	3

Course Number	**PH5202**
Course Credit	2-1-0-3
Course Title	General Relativity and Cosmology
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course provides a basic review of general relativity and presents a beginner level introduction to the science of understanding the origin, structure, and evolution of our universe. Based on the introductory text by B. Ryden, this semester-long course is aimed at graduate and undergraduate students with a keen interest in cosmology as a research discipline.
Prerequisite	Nil
Course Outline	Brief review of special theory of relativity, equivalence principle, describing curvature – Riemannian spacetime, generalized coordinates, review of tensor algebra and calculus, metric, Christoffel connections, geodesic equation, metric as a classical field, Reimann curvature tensor, Ricci tensor and scalar, Einstein action, Einstein equations, FRW metric, proper distance; Cosmological observations: dark night sky, isotropy and homogeneity, redshift, cosmic particles, cosmic microwave background – overview of the CMB spectrum, recombination, temperature fluctuations; the standard model of the universe (ΛCDM); Friedmann equation, equation of state, cosmological constant, single component universe – spatially flat, radiation, and matter dominated; cosmological parameters – Hubble constant, deceleration parameter; introduction to dark matter; The inflationary universe: flatness problem, horizon problem, monopole problem, the paradigm of inflation, physics of inflation – example of a scalar field driven inflation, advances of inflation model building, confronting inflation models with observation, primordial gravitational waves.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quiz, Seminar, Mid-semester and End-semester examination
Suggested Readings:	**Textbooks:** • Introduction to cosmology, B. Ryden, Cambridge Univ. Press, 2016. • Modern cosmology, Scott Dodelson, Academic Press, 2003. • Spacetime and Geometry: An introduction to general relativity, S. Carroll, Cambridge, 2019. **References:** • Cosmology, D. Baumann, Cambridge, 2022. • A first course in general relativity, B. Schutz, Cambridge, 2009. • Introduction to Cosmology, J. V. Narlikar, Cambridge Univ Press, 2002. • Gravitation and cosmology: Principles and applications of the general theory of relativity, S. Weinberg, Wiley, 1972.

Course Number	**PH5203**
Course Credit(L-T-P-C)	2-1-0-3
Course Title	Nanoelectronics
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	Students will learn basic concepts of nanoelectronics, nanodevices, molecular electronics and spintronics. Role of quantum mechanics behind nanoelectronics will be explored to explain many exotic phenomena in nanoscale. This course will describe the principle and the operation of Nano electronic and spintronics devices.
Course Content	Nanoelectronics: Why? Device scaling, Moore's law, limitations, role of quantum mechanics, Feynman's nanobot; Nanostructures: Impact, technology and physical consideration; Mesoscopic observables: Ballistic transport, phase interference, universal conductance fluctuations, weak localization; Carrier heating; Novel molecules (Pentacene, carbon nanotube, Fullerenes and its derivatives etc.) and conjugated polymers (Polyacetylene, P3HT, PEDOT:PSS etc.); Preliminaries : Basic Quantum mechanics and Fermi statistics, Metals, Insulators and Semiconductor, Density of states (DOS) in 0D-3D, DOS in disordered materials, Physics of organic semiconductors: concept of HOMO and LUMO, band gap etc. ;Two terminal quantum dot and quantum wire devices: Equilibrium in two terminal devices, Current flow in the presence of a bias, numerical technique for self-consistent estimation of V-I ,Current flow, quantum of conductance, Landauer theory; SET as a FET: Ballistic quantum wire FETs, conventional MOSFETs, CMOS, short channel and narrow width, hot electron effect, punch-through and thin gate oxide breakdown, OFET;
Learning Outcome	Complies with PLO 1, 2(a) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• David Ferry, Transport in Nanostructures Cambridge Univ. Press, 1995. • M. Baldo, Introduction to Nanoelectronics, Lecture Notes MIT, 2011.
References:	• S. Datta, Electronic Transport in Mesocopic Systems; Cambridge University Press, 1995. • S. Datta, Quantum Transport: Atom to Transistor; Cambridge University Press, 2005. • M. Lundstrom and J. Guo, Nanoscale Transistors; Physics, Modeling, and Simulation, Springer, 2006. • P.W. Atkins and R.S. Friedman, Molecular Quantum Mechanics; Oxford University Press, 3rd Edition, 1997. • M. Stepanova and S. Dew, Nanofabrication: Techniques and Principles; Springer-Verlag, 2012. • Rainer Waser, Nanotechnology

Course Number	**PH5204**
Course Credit	2-0-2-3
Course Title	Measurement Techniques
Learning Mode	Class lectures, assignments, discussions, hands-on experience and laboratory report
Learning Objectives	The objective of this course is to introduce a variety of measurement techniques that are required for materials characterization and their applications. Students gain hands-on experience of various instruments with a basic knowledge of their working principles. One of the most interesting part of this course is the error analysis. This allows experimental physicists to estimate how large the uncertainties are in a particular measurement and how to reduce them when necessary.
Course Description	The course covers a variety of measurement techniques which are part and parcel of any research and development laboratory. Together with the working principle, different modes of operation and different types of information extraction are included. Methods for making proper measurements with suitable error analysis techniques are included which are important for any serious experimentalist.
Course Outline	Basics of measurement: uncertainty in measurements, Comparison of measured & accepted values and Two measured values, checking relationships with a graph, Fractional uncertainties, multiplying two measured numbers, Propagation of uncertainties; Low level DC measurement of voltage, current and resistance, C-V and Impedance spectroscopy; Deep Level Transient Spectroscopy, Hall effect and Time of Flight methods for charge carriers; Magnetic Response using SQUID magnetometer and VSM; Dynamic light scattering, UV-VIS-NIR spectro-photometer, Fluorimeter & Ellipsometry, FTIR, Raman spectroscopy; Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Scanning Tunneling Microscopy (STM), Atomic Force Microscopy (AFM); X-ray diffraction (XRD) and grazing angle XRD; Quantum second-order correlation
Learning Outcome	Complies with PLO 1a 1b, 3
Assessment Method	Laboratory report, Mid-semester and End-semester examination
Suggested Readings:	• John R. Taylor, An Introduction to Error Analysis, Univ. Science Books, 2nd Edition, 1997. • Milton Ohring, Materials Science of Thin Films, Academic Press, 2nd Edition,2006.

Course Number	**PH5205**
Course Credit	2-1-0-3
Course Title	Quantum Optics & Quantum Information
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course provides fundamental knowledge in Quantum Optics required for pursuing research in this area and also it gives an introduction to Quantum Information and its engineering applications.
Course Outline	Basic Concepts in Quantum Optics; Quantization of free electromagnetic field; Fock or number states, Quadrature of the fields, Coherent & Squeezed states, Photon added & subtracted coherent state, Schrodinger cat state and the cat paradox; Q-representation and Wigner-Weyle distribution; First & second order Coherence, Correlation function; Hanbury Brown-Twiss experiments, Atom-field interaction; Laser without inversion, Quantum theory of laser-density operator approach; Atom optics; Open quantum system, Master equation; Cavity quantum electrodynamics (cavity-QED), Jaynes-Cummings model, dispersive atom-field interaction in a cavity; Laser Cooling;Quantum bits (Qubits), Bloch sphere, Quantum gates (single & two qubit); Quantum Entanglement, Bell's Inequality; Quantum Algorithms; Principles of Teleportation;Examples of Quantum information processing in physical systems: cavity-QED, Ultracold neutral atoms etc.; Current research and development in Quantum Optics & Quantum Information;
Learning Outcome	Complies with PLO 1a 2a 2b
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	▪ Quantum optics, M.O.Scully& M. Suhail Zubairy, Cambridge Univ. Press, New York, 2008. ▪ Quantum Optics, Girish S. Agarwal, Cambridge Univ. Press, New York, 2013. ▪ Quantum Computation & Quantum Information, M. A. Nielsen & I. L. Chuang, Cambridge Univ. Press, UK, 2000.
References:	▪ Quantum Optics: An Introduction, Mark Fox, Oxford Univ. Press, New York, 2014. ▪ The Quantum Theory of Light, Rodney Loudon, Oxford Univ. Press, New York, 2000. ▪ Quantum Optics, Klauder & Sudarshan.

Course Number	**PH5206**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Quantum Transport in Mesoscopic Systems
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	Students will learn theory of quantum transport in low-dimensional systems and apply them to understand and explain experimental observations on electron and thermal transports in mesoscopic systems.
Course Content	**Introduction:** Introduction to mesoscopic physics, basic length and energy scales, quantum structures, transport regime, Boltzmann transport equation **Diffusive transport:** Drude model, Einstein relation, classical size effect, weak localization **Ballistic transport:** Conductance quantization, Landauer Formula, Landauer-Büttiker formalism, Non-Equilibrium Green's function formalism **Transport in Coulomb blockade (CB) regime:** Rate equations, Sequential tunneling, CB oscillations, CB staircase. **Heat Transport**: Heat current, thermal conductance, See beck and Peltier coefficients **Quantum Hall effect:** Landau levels, edge states, quantum Hall effect (integer and fractional) **Noise in mesoscopic systems**: Current fluctuation, phase breaking, thermalization, inelastic scattering
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination and End-semester examination
Suggested Readings:	
Textbooks:	• Introduction to Mesoscopic Physics, 2nd Edition, Y. Imry, Oxford Univ. Press, 2008. • Mesoscopic Physics: An introduction, C. Harmans, TU Delft, 2003. • Quantum Transport, Lecture Notes, Yuri M. Galperin, Lund Univ., 1998. • Quantum Transport: Atom to Transistor, S. Datta, Cambridge Univ. Press, 2005. • Quantum Transport. Introduction to Nanoscience, Y.V. Nazarov, Y.M. Blanter, Cambridge Univ. Press, 2009.
References:	• Transport in Nanostructures, David Ferry, Cambridge Univ. Press, 1995. • M. Baldo, Introduction to Nanoelectronics, Lecture Notes, MIT, 2011. • S. Datta, Electronic Transport in Mesocopic Systems; Cambridge Univ. Press, 1995.

Course Number	**PH5207**
Course Credit	3-0-0-3
Course Title	Condensed Matter Physics-II
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Content	Review of Crystal structures, crystal symmetry, centrosymmetric and non-centrosymmetric crystalsand their properties **Correlated Electrons:** Fermi-Liquid Theory, Hartree-Fock theory and beyond, Density Functional Theory, Model Hamiltonians (Hubbard model, t-j model and etc.) **Magnetism:** Weiss theory of ferromagnetism, Curie-Weiss Law for susceptibility, Heisenberg model for magnetic ordering, Spin chain, XY model, Spin waves and magnons, magnon contribution to specific heat, Bloch's $T^{3/2}$ Law, Antiferromagnetic order, Neel Temperature, Ferromagnetic domains, Magnetic anisotropy energy, hysteresis. **Dielectric and Optical properties:** The dielectric function: the dielectric function for a harmonic oscillator, dielectric losses of electrons, Kramers-Kronig relations, Interaction of phonons and electrons with photons, Dielectric function of an interacting electron gas (Lindhard's expression), Static screening, Thomas-Fermi theory of Screening, Screened impurity, Kohn effect, Friedel Oscillations and sum rule, Dielectric constant of semiconductor, Plasma oscillations, Optical properties of metals, skin effect and anomalous skin effect. **Ferroelectrics:** Linear and Non-linear dielectrics, Langevin theory of dielectrics, Ferroelectric crystals, Classification of ferroelectric crystals, Polarization catastrophe, Soft optical phonons, Landau theory of phase transition: first and second order transition. **Superconductivity:** Ginzburg-Landau theory, BCS wavefunction, Energy gap, BCS ground state, unconventional superconductor, Josephson effect, SQUID
Suggested Readings:	
Textbooks	• N. W. Ashcroft and N. D. Mermin, Solid State Physics, HBC Publ., 1976. • C. Kittel, Introduction to Solid State Physics, Wiley India, 2009. • Dielectric Phenomena in Solides, Kao, Elsevier • Broadband Dielectric Spectroscopy, F Karmer & A Schonhals • Principles of the theory of Solids, J.M. Ziman, Cambridge Univ. Press.
References	• A. J. Dekker, Solid State Physics, Macmillan, 2009. • Dielectric Relaxation in Solids, A. K. Jonscher • M. A. Omar, Elementary Solid State Physics, Addison-Wesley, 2009.

Course Number	**PH5208/PH5112**
Course Credit L-T-P-C	3-0-0-3
Course Title	Introduction to nonlinear dynamics and chaos
Learning Mode	Lectures and Tutorials
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course will help the students to understand the concept and method of theory of dynamical system as well as its applications to physics and engineering.
Course Content	Dynamical system, one dimensional flows: Flows on the line, fixed points and stability, linear stability analysis, Potentials, Solving equaton on the computer, flows on the circle, physical examples like oscillator with and without damping, Bifurcations in one dimensional systems and their classification. Two-Dimensional Flows: Linear Systems and classification, limit cycle, Poincare-Bendixson theory, Bifurcations in two dimensions. Chaos: One dimensional map, Stability, Liapunov exponent, fractals, cantor set. Elementary Fluid Dynamics: Navier-Stokes equation, Turbulent flows.
Learning Outcome	Complies with PLO 1, 2 and 3
Assessment Method	Assignments, Quizzes, Presentation, Mid-semester examination and End-semester examination
Suggested Readings:	**Textbooks:** **4.** Nonlinear Dynamics & Chaos, S. H. Strogatz, CRC Press, 2018. **5.** Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers, D. W. Jordan and P. Smith, 4th ed., Oxford, 2007. 6. Fluid Mechanics, P. K. Kundu, I. M. Cohen and R. David, 6th ed., Academic Press, 2015. **References:** 3. Introduction to Dynamics, I. Percival and D. Richards, Cambridge University Press, 1983. 4. Fluid Mechanics, L. D. Landau, E. M. Lifshitz and L. P. Pitaevskii, Course on Theoretical Physics, Vol. 6, 2nd ed., Elsevier, 2010.

Course Number	**PH5209**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Ultrafast Optics and Spectroscopy
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2a and 3
Course Description	Students will be equipped with ultrafast lasers, their pulsing methods with linear and non-linear spectroscopic methods. Their usages in applications to research in imaging, nanoscopy and excitonic dynamics
Course Content	Ultrafast optics: Fundamentals of non-linear optics, Linear and nonlinear pulse shaping processes: second order, third order, higher-order non-linear phenomenon, Dispersion, Pulse compression; Chirped Pulse; Time Resolution, Optical solitons Laser principles: Single- and multi-mode laser dynamics, Q-switching, Active and passive mode-locking. Pulse characterization: Autocorrelation, frequency resolved optical gating (FROG), Spectral phase interferometry for direct electric field reconstruction (SPIDER); Noise in mode-locked lasers and its limitations in measurements; Laser amplifiers, optical parametric amplifiers, and oscillators; Pump-probe techniques, Four-wave Mixing, Time-resolved fluorescence, Up-conversion, THz-TDS, Higher harmonic generation. Applications of ultrafast spectroscopy: Super-resolution imaging, Exciton dynamics in chemistry and material science, Exciton dynamics in semiconductor nanocrystals. Multiphoton spectroscopy. Nanoscopy. Ultrafast transient absorption. Attoscience.
Learning Outcome	Complies with PLO 1a, 2 and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Laser Fundamentals, W. T. Silfvast, 2nd Ed., Cambridge Univ. Press. • Nonlinear Optics, Robert Boyd, 3rd Ed., Academic Press. • Advanced Time-Correlated Single Photon Counting Applications, Wolfgang Becker, Springer. • Ultrafast Dynamical Processes in Semiconductors, Kong-Thon Tsen, Springer. • Ultrafast Infrared Vibrational Spectroscopy; M. D Fayer, CRC Press.
References:	• Recent Advances in Ultrafast Structural Techniques, Sciaini, Appl. Sci. 9, 1427, 2019. • Femtosecond Infrared Spectroscopy of Semiconductors and Semiconductor Nanostructure, Physics Report, 1999, 321, 253. • Ultrafast studies of single semiconductor and metal nanostructures through transient absorption microscopy. Chem. Sci. 2010, 1 303.

Course Number	**PH5210**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Magnetism: Fundamentals to Application
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	Equips the students with the fundaments and applications of magnetism, magnetic materials, measurement techniques and spintronics. It allows them to develop advanced concepts and apply the knowledge in both research and industrial scenarios.
Course Content	Introduction - Magnetic moment, Bohr magnetron, magnetization, Field and Susceptibility; Quantum mechanics of spin: angular momentum, Pauli spin matrices, spin-spin coupling; Magnetic field generation: electromagnet, superconducting magnet; Diamagnetism, Paramagnetism Interactions - Dipolar interaction; Exchange interaction: direct, indirect, double, anisotropic etc.; ferromagnetism: Weiss model, molecular field; Antiferromagnetism; Ferrimagnetism; Helical magnetic order; Superparamagnetism, Spin Glass and frustration, measurements of magnetic order Order and Broken Symmetry - Landau theory of ferromagnetism; Heisenberg and Ising models; consequences of broken symmetry; phase transition; Excitations: magnon, Bloch's $T^{3/2}$ law, Mermin-Wagner-Bereziniskii theorem, Spin waves; Domains: Domain wall, Magnetocrystalline anisotropy, Domain wall width, formation, Stoner-Wohlfarth model, Soft and Hard magnetic materials Magnetism in metals – Free electron model; Pauli paramagnetism; Landau diamagnetism; Magnetism in electron gas; RKKY interaction, Two-dimensional magnets
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a), 2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Magnetism in Condensed Matter, Stephen Blundell, Oxford Univ. Press. • Introduction to Spintronics, Supriyo Bandyopadhyay, CRC press, Taylor & Francis Group. • Magnetism and Magnetic Materials, J. M. D. Coey, Cambridge Univ. Press. • Introduction to Magnetic Materials, 2nd Edition, L. C. Cullity and C. D. Graham, IEEE Press, Willey. • Handbook of Spin Transport and Materials and Magnetism, Editors - Evgeny Y.Tsymbal and Igor Źutić, CRC Press - Taylor & Francis Group. • Magnetism: From Fundamentals to Nanoscale Dynamics, Joachim Stöhr, Hans Christoph Siegmann, Springer Verlag. • Principles of Nanomagnetism, Guimarães, Alberto P., Springer, 2009.
References:	• Handbook of Spin Transport and Magnetism, Eds., Evgeny Y. Tsymbal, Igor Zutic, Taylor & Francis, 1st Edition. • Advances in Nanoscale Magnetism, Proceedings of the International Conference on Nanoscale Magnetism ICNM-2007, June 25 -29, Istanbul, Turkey, Series: Springer Proceedings in Physics, Vol. 122. • Lectures on Magnetism, Eugene Chudnovsky and Javier Tejada, Rinton Press, 1st Edition.

	• Introduction to Magnetism and Magnetic Materials, David Jiles, Chapman & Hall, 1998.

Course Number	**PH5211**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Ferroic Phenomena
Learning Mode	Lectures
Learning Objectives	The objective of the course is to introduce the student to the dielectric and ferroelectric properties of materials. Also, the dielectric and ferroelectric phenomena at nanoscale materials are elaborately taught. The important objective is to teach the applications of dielectric and ferroelectric materials and devices. The applications of dielectric and ferroelectric materials for energy storage device applications are elaborately taught in this course. Another important aspect is to realize the student the importance of dielectric and ferroelectric materials in modern technology.
Course Description	The course discusses different kinds of dielectric and ferroelectric materials and their physics formulations. The dielectric and ferroelectric phenomena at the nanoscale are discussed in this course. Also, pyroelectric, antiferroelectric, and relaxor ferroelectric are discussed in this course. Construction of supercapacitor and other devices are discussed here. Multiferroic. Magneto-electric and magneto-dielectric phenomena are discussed elaborately.
Course Content	Introductory remarks on classical concepts of electrostatics and Maxwell e.m. field equations; Concept of dielectric constant for nanostructures; Quantum approach for carriers in dielectrics; Electric polarization and relaxation – frequency and temperature dependence; Optical properties and radiative process in dielectric heterostructures & nanostructures; Photoemission, Luminescence, Photoconduction, Quantum yield and quantum efficiency; Transport in nanostructure networks (e.g.; tunneling, hopping, coulomb blockade etc.), Transitions between electrical conductivity, Transient phenomena, Charge carrier injection from electrical contacts; Role of defects and impurities in transport properties; Dielectric properties of metals, semiconductors and insulators (with examples of polymer, ceramics and composites). Spontaneous polarization and origin of Ferroelectricity; Phenomenology of Ferro, Antiferro, Pyro and Piezoelectric effects; Ferroelectric memory and its application for high density data storage; Charging of a dielectric nanostructure and mechanism of charge storage in it; Electrets and their applications; Ferroelectric-insulator-semiconductor junctions. Non-radiative and relaxation processes – multi-phonon capture at point defects, hot carrier relaxation; Electro-optic processes – Electro-optic, Photo-refractive and Magneto-optic effects; Elementary idea of Magneto-dielectric effect and Multiferroicity, Magnetoelectricity and Magnetoelectric coupling; Applications of multiferroicity and magnetoelectricity; Dielectric breakdown phenomena.
Learning Outcome	Complies with PLO 2a, 2b
Assessment Method	Assignments, min projects, Quizzes, Mid-semester examination, and End-semester examination.
Suggested Readings:	
Textbooks:	• Nanostructures: Theory & Modelling; C. Delerue, M. Lannoo, Springer, 2004. • Dielectric Phenomena in Solids, k. C. Kao, Academic Press, 2004. • Broadband Dielectric Spectroscopy, F. Kremer and F. Nicholas. Springer, 2003. • Ferroelectric Devices, K. Uchino, Marcel Dekker, 2000. • Ferroelectric Thin Films, M. Okayama & Y. Ishibashi (eds.), Springer, 2004.
References:	• Handbook of Advanced Electronic and Photonic Materials and Devices: Ferroelectrics & Dielectrics, Vol. 4, H. S. Nalwa (Ed.), Academic Press, 2001.

	• Handbook of Advanced Electronic and Photonic Materials and Devices: Nonlinear Optical Materials, Vol. 9, H. S. Nalwa (Ed.), Academic Press, 2001. • Encyclopedia of Nanoscience & Nanotechnology, Vol. 5, H. S. Nalwa (Ed.), American Scientific Publishers, 2004

Course Number	**PH5212**
Course Credit	2-1-0-3
Course Title	Materials for Engineering Applications
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course is designed to provide specialized knowledge related to the field of Materials for Engineering Applications.
Course Outline	Orientation: Why materials? Functionality driven material (re)search; Extraction, synthesis, processing, and characterization of materials. Structural Materials: Introduction to Alloys, Ceramics, Polymers and Composites; Preparation, Processing and Applications; Elastic and Plastic deformation, Residual stress, Hardness, Fracture, Fatigue, strengthening and forming, fracture resistance, fatigue life, creep resistance. Optical Materials: Introduction to optical materials; Interaction of light with electrons in materials; Applications as dielectric coatings, electro-optical devices, optical recording, optical communications. Magnetic Materials: Properties and processing of magnetic materials; Field, Induction, Magnetization and Hysteresis; Applications as Permanent magnets, Magnetic recording and sensing. Electronic Materials: Si as material for microelectronics and photovoltaic, preparation, processing and applications; III-V and II-VI semiconductors and optoelectronic applications; Thermoelectric materials, figure of merit, thermoelectric generators and refrigerators; Superconducting Materials and properties, applications including magnets, magneto-encephalography, Josephson junction, SQUID; Conducting Polymers, synthesis and applications; Ferroelectric materials, piezoelectricity and applications; Shape memory alloys and applications.
Learning Outcome	Complies with PLO 2a, 2b
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Materials Science for Engineering Students, Traugott Fischer, Academic Press, 2009.
References	• The Structure and Properties of Materials, J.W. Morris, Jr., McGraw Hill, 2005. • Principles of Electrical Engineering Materials and Devices, S. O. Kasap, McGraw-Hill, 2005.

Sl. No.	Subject Code	Departmental Elective - IV	L	T	P	C
1.	PH5213	Nanoionics: Concepts and Technological Applications	3	0	0	3
2.	PH5214	Computational Physics	2	0	2	3
3.	PH5215	Scanning Probe Microscopy	2	1	0	3
4.	PH5216	Biophotonics	2	1	0	3
5.	PH5217	Magnetic Materials and Applications	2	1	0	3
6.	PH5218	Fourier Optics and Holography	2	1	0	3
7.	PH5219 /PH5113	Quantum Field Theory	2	1	0	3
8.	PH5220	Particle Physics	2	1	0	3
9.	PH5221	Soft Matter Physics	3	0	0	3
10.	PH5222	Quantum Materials	2	1	0	3
11.	PH5223	Low Temperatures Techniques	2	0	2	3

Course Number	**PH5213**
Course Credit(L-T-P-C)	3-0-0-3
Course Title	Nanoionics: Concepts and Technological Applications
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1, 2 and 3
Course Description	This course provides detailed understanding of Concepts and Technological Applications in Nano-ionics
Course Content	Introduction, solid state ionics vis-à-vis solid state electronics, Principles of ionic conduction in ordered and disordered nanostructures; Superionic materials classification – Crystalline anionic and cationic conductors, mixed ionic and electronic conductors, structural factors responsible for high ionic conductivity; Brief review on physical techniques for analysis of ion conducting solids; Transport properties and Ion dynamics; Ion transport in homogeneous and heterogeneous medium – Ion conducting glasses, ceramics, polymers and composites; Ion Transport Models Phenomenological models, Free volume theory, Configurational entropy model, Jump relaxation and Ion hopping model, Bond percolation model and Effective medium theory; Concepts and feasibility of ion conducting polymer nanocomposites and nanocrystalline ceramics. Material problems and processing techniques; Technological applications of ion conducting solids; Design, Fabrication and Evaluation of Solid State Lithium Batteries, Supercapacitors (EDLC and Redox), Fuel Cells (PEM Fuel cell, SOFC), Gas sensors and display devices. Thermodynamics and mass transport in solid state batteries. Battery performance and electrode kinetics. Double layer and other polarization effects at solid /solid interface; Fuel Cells as micro-power houses, Power conditioning and control of fuel cell systems.
Learning Outcome	Complies with PLO 1a, 2a and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Superionic Solids: Principles and Applications, S. Chandra, North Holland, 1981. • Solid State Ionics, T. Kudu and K. Fueki, Kodanasha-VCH, 1990. • Lithium Batteries: Research, Technology & Applications, Greger R. Dahlin, Kalle E. Strøm, Nova Science Pub Inc, 2010. • Energy Storage, R. A. Huggins, Springer, 2010. • Electrochemical Supercapacitors: Scientific Fundamentals & Technological Applications, B. E. Conway, Kluwer Academic, 1999. • Fuel Cell Technology, Nigel Sammes (ed.), 1st edition, Springer, 2006. • Clean Energy, R. M. Dell & D. A. J. Rand, Royal Society Pub., 2004. • Fuel Cell Engines, Matthew M. Mench, John Wiley & Sons, 2008.
References:	• Solid State Electrochemistry, P. G. Bruce (ed.), Cambridge University Press, 1995. • The CRC Handbook of Solid State Electrochemistry, P. J. Gellings & H. J. M. Bauwmeester, CRC Press, 1997. • Solid State Electrochemistry II: Electrodes, Interfaces and Ceramic Membranes, V. V. Kharton (ed.), Wiley-VCH, 2009. • Fuel Cell Technology Handbook, G. Hoogers (ed.), CRC Press, 2003 (ISBN: 0-8493-0877-1). • Fuel Cell Technologies: State & perspectives; N. Sammes, A. Smirnova and O. Vasylyev (eds.), Springer, 2004.

Course Number	**PH5214**
Course Credit	2-0-2-3
Course Title	Computational Physics
Learning Mode	Lecture & Laboratory
Learning Objectives	To make students capable of solving specific advanced physics problems using the techniques developed in PH427 (Numerical Techniques).
Course Description	The student will learn computationally solving problems related to Quantum scattering, Many-electron formalism, Classical and quantum molecular dynamics, Statistical physics etc. The course has class room discussion which will be completed in computational lab by developing a code based on it.
Course Outline	Recapitulation of numerical techniques and errors of computation (rounding, truncation); Classical molecular dynamics simulations, Verlet algorithm, predictor corrector method, Continuous systems, hydrodynamic equations, particle in a cell and lattice Boltzmann methods; Schrodinger equation in a basis: numerical implementation of Numerov method, matrix methods and variational techniques; applications of basic functions for atomic, molecular, solid-state and nuclear calculations; Elements of Density functional theories; Monte Carlo simulations, Metropolis, critical slowing down and block algorithms with applications to classical and quantum lattice models.
Learning Outcome	Complies with PLO 1b, 3
Assessment Method	Mid-term written examination, Mid-term lab examination, End-term written examination, End-term lab examination, Assignment & Quiz
Suggested Readings:	
Textbooks:	• J. M. Thijssen, Computational Physics, Cambridge Univ. Press, 2nd Edition, 2007. • Tao Pang, An Introduction to Computational Physics, Cambridge Univ. Press, 2ndEdition, 2006. • Steven E. Kooning and Dawn C. Meredith, Computational Physics, Westview Press, 1990. • An Introduction to Computer Simulation Methods: Applications to Physical Systems, 3rdEdition, Harvey Gould, Jan Tobochnik, Wolfgang Christian, Addison-Wesley, 2006.
References:	• Rubin H. Landau, Manuel José Páez Mejía, Cristian C. Bordeianu, A Survey of Computational Physics: Introductory Computational Science, Volume 1, Princeton Univ. Press, 2008. • Werner Krauth, Statistical Mechanics: Algorithms and Computations, Oxford Masters Series in Physics, 2006.

Course Number	**PH5215**
Course Credit	2-1-0-3
Course Title	Scanning Probe Microscopy
Learning Mode	Lectures, assignments, discussions, hands-on experience
Learning Objectives	The objective of this course is to present a unified discussion on the fundamentals of atomic force microscopy and scanning tunneling microscopy. This will allow students to learn materials characterization and manipulation at the nanoscale using these probe based techniques.
Course Description	The course covers instrumental aspects of scanning probe microscopy including atomic force microscope and scanning tunneling microscope. The course summarizes the basics of the tip-sample interaction and contact mechanics. In addition, this course introduces probe based physical property measurement of materials with nanoscale resolution.
Course Outline	**Tip-Surface Interaction** **AFMNon-contact regime** Intra-Molecular Interactions, Electric Dipoles, Inter-molecular interactions: Physical models, ion-dipoles, Keesom forces, Dispersion Force **AFM Contact regime** Hamaker theory, surface energies, Dejaugin approximation, contact mechanics, Hertz model, JKR model, DMT model. **Atomic Force Microscope (AFM)** AFM components, AFM calibration, analysis of AFM images in each mode. **Force Spectroscopy** Cantilever mechanics, Approach-retract curves, Processing Force curves, Modulus and adhesion Maps, Lateral Force Microscopy, Conducting Atomic Force Microscopy, Nanoindentation. **Point Mass Model of Dynamic AFM,** frequency response, conservative and dissipative interaction forces. **Analytical theory of Dynamic AFM:** Excited probe interacting with sample (linear theory), Amplitude and Frequency modulation AFM, Non-linear/dissipative interactions, Attractive and Repulsive Regimes and Phase Contrast Modualtion AFM. **Scanning Tunneling Microscope (STM)** Quantum tunneling, WKB approximation for field emission, STM instruments and its components, scanning tunneling spectroscopy, Inelastic electron tunneling spectroscopy, STM image analysis. **Special AFM techniques for Electrostatics/Magnetic/Biological systems** Measuring Electrostatic Forces and Magnetic Forces, Dynamic AFM in Liquid, Scanning non-linear dielectric microscopy (SNDM) for measuring defect state densities at interfaces, Memristive applications, organic electronics and spintronics, Atomic/molecular manipulations, AFM-based lithography, spin-polarized STM. MFM, PFM, NSOM **(ADD other SPM techniques)**
Learning Outcome	PLO 1a, 1b, 3
Assessment Method	Tutorials, Assignments, Mid-semester examination, End-semester examination
Suggested Readings:	• Scanning Probe Microscopy: Atomic Force Microscopy and Scanning Tunneling Microscopy, Bert Voigtlander, Springer-Verlag Berlin Heidelberg, 2015. • Scanning Probe Microscopy and Spectroscopy: Methods and Applications, Roland Wiesendanger, Cambridge Univ. Press, 1994. • Scanning Probe Microscopy: Electrical and Electromechanical Phenomena at the Nanoscale, Sergei V. Kalinin, Alex Gruverman, Springer-Verlag New York, 2007

Course Number	**PH5216**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Biophotonics
Learning Mode	Lectures
Learning Objectives	Theory and fabrication details of several optical and photonic devices for several biological and biomedical applications
Course Description	This course is designed to provide specialized knowledge related to an emerging field of optics and photonics.
Course Outline	• Fundamentals of light-matter interaction [absorption, fluorescence, phosphorescence, Raman scattering, Mie-scattering, Second harmonic generation (SHG) and two photon absorption], Introduction to biological cells, viruses, protein molecules • Optical imaging of cells (using various optical microscopes): Optical microscopy, Bio-imaging with confocal fluorescence microscope, evanescent wave microscope, SHG and two photon microscopes, Different techniques to achieve super resolution with optical microscopes; quantum imaging. • Biodetection in real time (using optical biosensors): Importance of biodetection in real time, detection of bioanalytes (virus/protein molecules) using evanescent based fiber-optic biosensor, photonic crystal biosensor and whispering gallery mode biosensor. • Förster resonance energy transfer (FRET) to study protein - protein interactions. • Supercontinuum sources for Biophotonic applications. • Optical trapping and manipulation for biomedical applications • Advanced photodynamic therapy (APT) • Nanoplasmonicbiophotonics: Introduction to Nanoplasmonics, Applications of nanoplasmonics in optical trapping, biosensing, APT, and Raman scattering of nanometer sized bioanalytes
Learning Outcome	Complies with PLO (2)
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• X. Shen and R. V. Wijk, *Biophotonics*, Springer, USA, 2005. • P. N. Prasad, *Introduction to Biophotonics*, Wiley-Interscience, New Jersey, 2003. • X. Shen and R. V. Wijk, *Biophotonics*, Springer, USA, 2005. • L. Pavesi and P. M. Fauchet, *Biophotonics*, Springer, Berlin, 2008. • B. D. Bartolo and J. Collins, *Bio-photonics: Spectroscopy, Imaging, Sensing and Manipulation*, Springer, Netherlands, 2009.
References	• R. K. Wang and V. V. Tuchin, *Advanced Biophotonics*, CRC press, New York, 2014.

Course Number	**PH5217**
Course Credit (L-T-P-C)	2-1-0-3
Course Title	Magnetic Materials and Applications
Learning Mode	Lectures
Learning Objectives	The objectives of the course are to introduce the student to the importance of magnetic materials and their application. The student will understand the magnetic sensors. Memory devices based on magnetic materials are elaborately taught. Different kinds of magnetoresistance are taught in this material. The physics formulation of magnetism is taught which helps to understand the magnetic materials. The permanent magnet is an integral part of modern technology which is taught in this course. Also, the objective of the course is to understand magnetism at the small size.
Course Description	The course discusses different kinds of magnetic materials. The different kinds of magnetoresistance are discussed here. The physics formulation of magnetism observations is discussed elaborately. Applications of magnetic materials in different technologies are discussed elaborately. Superconductivity is discussed along with its applications.
Course Content	Atomic magnetism, diamagnetism and paramagnetism, Hund's rule, Solid state magnetism, 3d transition metals and 4f rare earths, Magnetic interactions, direct exchange and indirect exchange, Magnetic order, Ferromagnetism, Ferrimagnetism, Antiferromagnetism, Spin glasses; Magneto-crystalline anisotropy, Shape anisotropy, Induced magnetic anisotropy, Stress anisotropy, Magnetic surface and interface anisotropy; Magnetic Domain structures and magnetization dynamics, Domain walls, Closure domains, closure domains, damping processes, ferromagnetic resonance; Magnetoresistivity, Anisotropic Magnetoresistance (AMR), Giant Magnetoresistance (GMR), Colossal Magnetoresistance (CMR), Tunneling Magnetoresistance (TMR), Spin polarization, Andreev reflection, Point contact Andreev reflection (PCAR) spectroscopy, BTK theory; Soft Magnetic Materials , Eddy currents, losses in electrical machines, applications in Transformers, Flux-gate magnetometers, recording heads, magnetic shielding, anti-theft systems; Hard Magnetic Materials, Permanent Magnets, operation and stability, applications in motors, loudspeakers, hard drives, wigglers, undulators; Magnetism in reduced dimensions, Atoms, Clusters, Nano-particles, Nanoscale wires, Thin films, Multilayers, Superparamagnetism, Exchange bias, Interlayer exchange coupling (non-magnetic spacer, AFM spacer), Spin engineering, Spin valves.
Learning Outcome	Complies with PLO 2a, 2b
Assessment Method	Assignments, mini projects, Quiz, Mid-semester examination and End-semester examination.
Suggested Readings:	
Textbooks:	• Magnetic Materials: Fundamentals and Applications, Nicola A. Spaldin, 2nd Edition, Cambridge Univ. Press.
References:	• Magnetism and Magnetic Materials, J.M. D. Coey, 1st Edition, Cambridge Univ. Press, 2010. • Principles of Magnetism and Magnetic Materials, K. H. J. Buschow and F. R. de Boer, Kluwer Academic Publisher, New York, 2004.

Course Number	**PH5218**
Course Credit	2-1-0-3
Course Title	Fourier Optics and Holography
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course gives introduction to diffraction and image formation. Fourier transforming property of a lens and applications of Holography.
Course Outline	Signals and systems, Fourier transform (FT), FT theorems, sampling theorem, Space-bandwidth product; Review of diffraction theory: Fresnel-Kirchhoff formulation, FT properties of lenses; Coherent and incoherent imaging. Basics of holography, in-line and off-axis holography, plane and volume holograms, diffraction efficiency; Recording medium for holograms; Applications of holography: display, microscopy; memories, interferometry, Non-destructive testing of engineering objects, Digital Holography, Digital holographic microscope, 3D display; Analog optical information processing: Abbe-Porter experiment, phase contrast microscopy and other simple applications; Coherent image processing: VanderLugt filter; joint-transform correlator; optical image encryption.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3(a)
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• J. W. Goodman, Introduction to Fourier Optics, 3rd Ed. 2005. • M. Born and E. Wolf, Principles of Optics, 7th Ed., Cambridge Univ. Press, 1999. • P. Hariharan, Optical Holography: Principles, Techniques, and Applications, 2nd Ed., Cambridge Univ. Press, 1996. • B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, 1991.
References	• E. G. Steward, Fourier Optics: An Introduction, 2nd Ed., Dover Publ., 2004. • Robert K. Tyson, Principles and Applications of Fourier Optics, IOP Publ., Bristol, UK, 2014. • U. Schnars and W. Jueptner, Springer, 2005. • Joseph Rosen, Holography, Research & Technologies, InTech, 2011.

Course Number	**PH5219/PH5113**
Course Credit	2-1-0-3
Course Title	Quantum Field Theory
Prerequisite	Quantum Mechanics
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This is an introductory course of Quantum Field Theory (QFT), which is the study of systems in which both special relativity and quantum mechanics are relevant. Students will learn basic concepts and techniques of QFT with special emphasis on Quantum Electrodynamics (QED). Students will learn to calculate the cross section for tree level QED Feynman diagrams. This course will help the students to develop the knowledge base necessary to pursue research in elementary particle physics or high energy physics, particle astrophysics, condense matter physics.
Course Outline	Classical Field Theory: Lagrangian formulation; Lorentz invariance; Noether's theorem and conserved currents, Hamiltonian Field Theory. Canonical quantization of free scalar fields: The Klein-Gordon Equation, Quantization of real and complex scalar fields, The Heisenberg Picture, Propagator. Quantization of Dirac fields: Dirac Equation, Clifford Algebras, Dirac Lagrangian and Hamiltonian, Plane Wave Solutions, Bilinear covariants, Trace formulas, Projection operators, Propagators. Interacting fields: Example of interactions, Interaction picture, Dyson's Formula, S-matrix, Wick's theorem, Feynman Diagrams, Feynman Rules. Quantization of EM field and Quantum Electrodynamics: Quantization of EM fields, Photon Propagator, Local gauge invariance leading to QED, Feynman Rules, Example of calculations for Amplitudes, Decay rates, cross-sections for lowest order QED processes, Crossing Symmetry. Brief review of Parity, Charge conjugation and Time reversal on scalar, Dirac and electromagnetic fields. Recitation: This will be on one of the topics listed above. Mini project: This will be on one of the topics listed above. Additional assignments: Related to above listed topics.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quizzes, Presentation, Mid-semester examination and End-semester examination
Suggested Readings:	
Textbooks:	• An Introduction to Quantum Field Theory -- M. Peskin and F. Schroeder; Westview Press, 1995. • A First Book of Quantum Field Theory -- A. Lahiri and P.B. Pal; Narosa Publishing, 2002. • Quantum Field Theory -- L. Ryder; Cambridge Univ. Press, 1996. • Quantum Field Theory and the Standard Model -- Mathew D. Schwartz, Canbridge Univ. Press, 2013.
References:	• The Quantum Theory of Fields, Vol. I & II – S. Weinberg; Cambridge Univ. Press, 2005. • Field Theory: A Modern Primer -- P. Ramond; Tylor and Francis, 2020. • Introduction to Gauge Field Theory -- D. Bailin & A. Love; CRC Press, 1993.

	• Relativistic Quantum Fields -- J.D. Bjorken and S.D. Drell; McGraw-Hill, 1965. • Quantum Field Theory -- F. Mandl and G. Shaw; Wiley, 2010. • Quantum Field Theory in a Nutshell -- A. Zee; Princeton Univ. Press, 2010. • Quantum Field Theory -- Itzykson and J.B. Zuber, Dover Publs., 2006.

Course Number	**PH5220**
Course Credit	2-1-0-3
Course Title	Particle Physics
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course deals with the basic properties of elementary particles, their interactions and decays. Students will learn basics of weak interactions, QCD, symmetries, symmetry breaking, the Standard Model and the origin of mass. This course will help the students to develop the knowledge base necessary to pursue research in elementary particle physics/high energy physics, particle astrophysics.
Course Outline	Natural Units; Basic overview of four fundamental interactions; Elementary Particles and their characteristics. Static model ($SU(3)_f$) of quarks; Eightfold way; Concept of colour, Concept of Asymptotic freedom and confinement; Summary of quantum numbers of all quark flavours. *Weak interactions:* Fermi theory, Calculation of decay widths of muon and charged pion ($\pi^{\pm}$). *Structure of Hadrons and QCD:* Elastic electron-proton (e-p) scattering, form factors, Deep-inelastic e-p scattering, structure fuctions, Bjorken scaling, Parton model, Mandelstam variables, Compton scattering and gluon emission scattering amplitudes and cross-sections in terms of Mandelstam variables, scaling violation. *Gauge theory of fundamental interaction:* Internal symmetries, Global and local gauge invariance. *Gauge theory of weak interaction:* Spontaneous symmetry breaking (SSB) and Higgs mechanism, Electroweak unification, Glashow-Weinberg-Salam model of electroweak symmetry breaking (EWSB) - $W^{\pm}$, Z^0 masses and fermion masses. Parity violation, CP violation, Quark Mixing and CKM matrix. Neutrino mass and neutrino oscillations; Reasons for looking Physics Beyond the Standard Model (Qualitative ideas). Collider Experiments: lepton vs Hadron collider (e.g., LEP, LHC etc.).
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Quarks and Leptons: An Introductory course in Modern Particle Physics, Francis Halzen and Alan D. Martin; John Wiley & Sons, 1984. • Introduction to High Energy Physics, D.H.Perkins, Cambridge Univ. Press, 2000. • Introduction to Elementary Particles, D. Griffiths, Wiley, 2008. • Gauge Theories in Particle Physics, T.-P. Cheng and L.-F. Li, Oxford Univ. Press, 1984.
References:	• An Introduction to Quantum Field Theory, M.E. Peskin and D.V. Schroeder; W. Press, 1995. • An Introductory Course of Particle Physics, Palash B. Pal; CRC Press, 2014.

	• Introduction to Gauge Field Theory, D. Bailin & A. Love, CRC Press, 1993. • Modern Elementary Particle Physics, G. Kane; Addison Wesley, 1987. • The Standard Model: A Primer, Burgess and Moore; Cambridge Univ. Press, 2012.

Course Number	**PH5221**
Course Credit	3-0-0-3
Course Title	Soft Matter Physics
Learning Mode	Lectures
Learning Objectives	Complies with program goal 1,2 and 3
Course Description	This course deals with the Forces, energies and time scales, Molecular order in soft matter and gives a description of Soft matter in nature
Course Outline	Unit I: Forces, energies and time scales in soft matter Thermodynamic and statistical aspects of intermolecular forces, Boltzmann distribution and chemical potential, pair potential, strong intermolecular forces – covalent and Coulomb interactions, Van der Waals forces, steric forces, hydrogen bonding, response of matter to a shear stress, viscoelastic behavior, relaxation time. Unit II: Molecular order in soft matter Phase transitions, order parameter, liquid crystallinity - nematic, cholesteric, smectic, columnar; colloids and gels, crystallinity in polymeric materials, weight dispersion in polymers, random walk models, dimensions of polymer chains, persistence length of flexible chains, radius of gyration, Flory-Huggins theory. Unit III: Soft matter in nature Supramolecular self-assembly, aggregation in amphiphilic molecules, soluble and insoluble monolayers, critical micellar concentration, effect of dimensionality and geometry, spherical and cylindrical micelles, bilayers and vesicles, biological lipid membranes, nucleic acids and proteins, surfactants, soaps and emulsions, technological applications of soft matter.
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3
Assessment Method	Assignments, Quizzes, Seminar, Mid-semester examination, End-semester examination
Suggested Readings:	
Textbooks:	• Soft Condensed Matter, R. A. L. Jones, Oxford Univ. Press, 2002. • Intermolecular and Surface Forces by Jacob N. Israelachvilli, Academic Press, Elsevier, 2011.
References:	• The Physics of Liquid Crystals, P.G. de Gennes and J. Prost, Oxford Univ. Press, 2003. • Principles of Condensed Matter Physics, P.M. Chaikin& T.C. Lubensky, Cambridge Univ. Press, 2004.

Course Number	**PH5222**
Course Credit	2-1-0-3
Course Title	Quantum Materials
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	The course covers various quantum mechanical phenomenon occurring in condensed matter systems and the ways to tune and control them, for designing various quantum-controlled operations to develop relevant devices and technologies.
Course Outline	Theories of electronic structure: Fermi Liquid Theory, Model Hamiltonian, Density Functional Theory Quantum ordering: Superconductivity; Quantum Criticality; Magnetism; Spin Ice and magnetic monopoles; Topological materials; Weyl Semimetal; Majorana Fermions; Skyrmions; Quantum hall effect; Dirac Materials and Van der Waals magnet; Moiré lattice and Twistronics; Metamaterials and photonic crystals Application: Qubits; quantum simulation; quantum technology (quantum communications, quantum sensing and metrology, and quantum computing) Experimental Probes: Large scale facilities (ex: Neutron, muon and Angle resolved photoemission spectroscopy, synchrotron beamlines); Local probes for quantum phenomenon
Learning Outcome	Complies with PLO 1(a),1(b), 2(a) and 3a
Assessment Method	Quiz and test , Mid sem exam and End term examination
Suggested Readings:	
Textbooks:	• J Annett, Superconductivity, Superfluids and Condensates, Oxford Univ. Press. • Quantum Magnetism, Ed., Ulrich Schollwöck, Johannes Richter, amian J. J. Farnell, Raymod F. Bishop, Springer • Topological Insulators, Shun-Qing Shen, Springer
References:	• A. Damascelli, Z. Hussain and Z.X. Shen, Rev. Mod. Phys. 75, 473, 2003. • A.J. Schofield, Contemp. Phys. 40, 95, 1999. • D. Shoenberg, *Magnetic Oscillations in Metals*, Cambridge Univ. Press. • C. Bergemann, A. P. Mackenzie, S. R. Julian, D. Forsythe, and E. Ohmichi, Adv. Phys. 52, 639 (2003) • H. Ibach and H. Luth, *Solid-state Physics: An Introduction to Principles of Materials Science* (Springer-Verlag) • N.W. Ashcroft and N.D. Mermin, *Solid State Physics*, Saunders College Publs. • Quantum Information, Stephen Barnett, Oxford Univ. Press • Quantum Hybrid Electronics and Materials, Eds., Yoshiro Hirayama, Kazuhiko Hirakawa, Hiroshi Yamaguchi, Springer • Principles of Neutron Scattering from Condensed Matter, Andrew T. Boothroyd, Oxford Univ. Press • Muon Spin Rotation, Relaxation, and Resonance: Applications to Condensed Matter, Alain Yaouanc, Pierre Dalmas de Réotier, Oxford Univ. Press • An Introduction to Synchrotron Radiation: Techniques and Applications, 2nd Edition, Philip Willmott, Wiley.

Course Number	**PH5223**
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Low Temperatures Techniques
Learning Mode	Lectures and Laboratory
Learning Objectives	Complies with Program Goals 1, 2 and 3
Course Description	Equips the students with the techniques in Low Temperature Physics and allows them to apply these techniques in both research and industrial scenarios
Course Content	Introduction to low temperature physics: Joule-Thompson Expansion, Generation and measurement of low temperatures; Liquid Nitrogen and Liquid Helium as a cryogen for achieving low temperatures-phase diagram, superfluid Helium and Helium-3; Cooling and Cryogenic Equipment, Dewars, Cryostats and Superconducting Magnets, pumps and plumbing, temperature sensing; Magnetic cooling; Dilution Refrigerators; Variable temperature inserts; Vibration isolation, electric and magnetic isolation; Bridges for susceptibility measurements; Cryogenic electronics, low temperature preamplifier, high frequency methods and electromagnetic compatibility; Materials compatible for low temperature system design; Safety at low temperatures; Applications: NMR, MRI, solid state quantum qubits, Tokamak
Learning Outcome	Complies with PLO 1(a), 1(b), 2(b) and 3
Assessment Method	Assignments, Quizzes, Mid-semester and End-semester examination
Suggested Readings:	
Textbooks:	• Robert C. Richardson and Eric N. Smith, Experimental Techniques in Condensed Matter Physics at Low Temperatures, Frontiers in Physics, Addison Wesley, 1988. • P. V. E. McClintock, D. J. Meredith, J. K. Wigmore, Low-Temperature Physics: An Introduction for Scientists and Engineers, Springer, 2012.
References:	• Frank Pobell, *Matters and Methods at Low Temperature*, 3rd Edition, Springer, 2007. • Randall Barron, *Cryogenic Systems*, 2nd Edition, 2021.

Sl. No.	Subject Code	Subject	L	T	P	C
1.	PH6101/6201	Physics of Complex Systems	3	0	0	3
2.	PH6102/6202	Physics of Nanoscience	3	0	0	3
3.	PH6103/6203	Semiconductor Processing: An Interdisciplinary approach	3	0	0	3

Course Number	**PH6101/6201**
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Physics of Complex Systems
Learning Mode	Lectures and Computational exercises
Learning Objectives	Complies with Program Goals 1, 2 and 3 Course objectives include: • To understand the fundamental principles governing complex systems. • To apply mathematical and computational techniques to model and analyze complex systems. • To explore real-world applications of complex systems in various fields such as climate science, economics, and social networks.
Course Description	This interdisciplinary course explores the universal aspects of physical behavior of complex systems. A complex system, characterized by interconnected or interwoven parts, can include ecological systems, economies, fluids, biological organisms, or strongly-correlated solids. The course draws from mathematics, nonlinear science, numerical simulations, and statistical physics. It begins with an overview of complex systems and then delves into modeling techniques using nonlinear differential equations, networks, and stochastic models. Throughout the course, students will model, program, and analyze a diverse range of complex systems, including dynamical and chaotic systems, cellular automata, and iterated functions. Through these, there will be ample scope for hands-on experience and a deeper understanding of complex systems emerging from elementary rules.
Course Content	A brief recap of Dynamical Systems; Complex Systems, ingredients, key features; Interdisciplinary approaches to studying complex systems and the role of Physics; Discrete and Continuous Time Models; implications of bifurcation, chaos and catastrophe; interactive simulations of complex systems, cellular automata, continuous field models; basics of networks, small world network; dynamical networks: Modeling, Network topologies and dynamics; Agent-based models; Examples including climate, epidemiology, forest-fire, strongly correlated electron systems, bioinformatics, belief propagation, internet, etc; Emergence and universal characteristics of complex systems
Learning Outcome	Complies with PLO 1(a), 1(b), 2(a) and 3
Assessment Method	Assignments, Quizzes, Mid-semester examination and End-semester examination
Suggested Readings:	**Textbooks:** 1. Hiroki Sayama, Introduction to the Modeling and Analysis of Complex Systems, Open SUNY (2015). 2. John H. Miller and Scott E. Page, Complex Adaptive Systems, Princeton Studies in Complexity Series (2007). 3. Nino Boccara, Modeling Complex Systems, Springer-Verlag Reprint (2024). **References:** 1. W. Krauth, Statistical Mechanics: Algorithms and Computations (Oxford Masters Series in Physics, 2006). 2. Albert-László Barabási, Linked: The New Science of Networks, Perseus Books (2002).

Course Number	**PH6102/6202**
Course Credit L – T – P – C:	3-0-0-3
Course Title	Physics of Nanoscience
Learning Mode	Lectures
Learning Objectives	The objective of the course is to develop basic understanding, type, synthesis about Nanoparticle. The wonderful game of physics playing behind bizarre physical properties of Nanoparticles is also dealt.
Course Description	The course first provides the fundamental physics knowledge that is required for the understanding of Nanoparticles, especially its physical properties. These are dealt in Module-1, and module 2. Module-3 is on properties of nanoscale materials. In Module-4, the approach to synthesis of Nanoparticles, Tools for realizing the nanoscale materials and Applications. .
Course Outline	Introduction, Structure, Length scales, Excitons, Quantum mechanics review, Various 1D potentials, Mathcad solutions, Particle in an infinite circle, Particle in a sphere, Confinement, Nondegenerate perturbation theory, Density of states: 3D, 2D, 1D, 0D, CB and VB states, 3D Fermi level, 2D and 1D density of CB and VB states, Vertical transitions, joint density of states, Einstein A and B coefficients, Pulsed experiment and lifetime, Radiative decay of excited state, Multiple pathway decay of excited state, Joint density of states, absorption, Interband transitions, Emission, Bands, WKB approximation, Properties of nanoscales: Mechanical properties, Magnetic properties and Electrical properties, Synthesis: Basics of thin film deposition, Lithography, Physical and Chemical synthesis, Applications of Nanoscience: Nanowire sensor, Quantum dot/dye photobleaching, Quantum dot/dye absorption/emission spectra, Density of states for lasing, Solar spectrum and QD absorption/emission spectra, Quantum dot LED schematic, Orthodox model of single electron tunneling, Coulomb Staircase.
Learning Outcome	Complies with 2a. 3
Assessment Method	Quiz and/or Assignments and Examinations
Suggested Readings:	**Test Books:** 1- Introductory Nanoscience: Physical and Chemical Concept, Masaru Kuno, Garland Science, 2011 **Reference Books:** 2- Nanomaterials, Nanotecnologies and Design: An introduction for Engineers and Architect, M. F. Ashby, Paulo J. Ferreira, D. L. Schodek, Elsevier, 2009. 3- Introduction to Nanotechnology; Charles P. Poole, Jr. and Frank J. Owens, Wiley – Interscience, **2003**. 4- Introductory Nanoscience: Physical and Chemical Concept, Masaru Kuno, Garland Science, 2011.

Course Number	**PH6103/6203**
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Semiconductor Processing: An Interdisciplinary approach
Learning Mode	Lectures
Learning Objectives	The objective of the course is to develop basic knowledge about how semiconductor technology/product is manufactured using various tools and approaches. Also, introduces various characterization methods adopted till now to realize high yield processes in semiconductor manufacturing.
Course Description	In beginning, course introduces about clean room and related functionalities with a fundamental question such as Why do we need clean room? Later, course provides the basic background of semiconductor available and used till now in semiconductor industries by answering questions like why do we need semiconductor and semiconductor-based devices? What kind of semiconductor materials are really useful for semiconductor technology? Then, course introduces importance of semiconductor surfaces and how these surfaces are prepared. Impurities, Importance of doping, dopants and doping densities. By taking an example of CMOS device, Design and layout methods are introduced. To realize these patterns/design, various lithography techniques are introduced. Later, deposition of various materials using various deposition techniques are introduced by highlighting the importance of parameters chosen for deposition. Wet and dry etching methods are introduced as successive process there after. Wet and wet chemistry is highlighted with process parameters adopted. Device fabrication steps and device characterization tools are introduced to know the device performance. At the end of this courses, device testing and device bonding is introduced in detail. Various related tools will be introduced to students wherever processes details are explained.
Course Outline	Introduction to clean room, process overview, Contamination, precautions and safety measures Background to semiconductor materials, Silicon wafers, cleaning steps (Solvent clean, Piranha clean, RCA clean, HF-dip), safety and emergency acts Semiconductor surface preparation, Surface oxidation process (wet and dry oxidation), Introduction to impurities, diffusion of impurities, ion implantation Device layout and design, Lithography, Etching processes, Sputtering techniques for deposition of oxides and metals, Chemical vapour deposition (CVD), Plasma enhanced chemical vapour deposition (PECVD), Atomic layer deposition (ALD) Introduction to MOS/CMOS devices and their applications, process optimizations and Process integration, I-V measurement, C-V measurement, Ellipsometer, Hall measurement, Nano-indentation test, Focused Ion Beam (FIB) technique Silicon wafer dicing, Chip bonding (Wedge and ball bonding), Pull testing for wire bonds
Learning Outcome	Complies with PLO 2b, 3
Assessment Method	Quizzes, Mid-semsester and End-semester examination
Suggested Readings:	• Fundamental of semiconductor Manufacturing and process control, Gray S. May, Costas J. Spanos, John Wiley and Sons, 2006.

	• Fundamental of Semiconductor Fabrication, Gray S. May, Simon M. Sze, Wiley India Pvt. Ltd., 2011. • Introduction to semiconductor materials and Devices, M. S. Tyagi, Wiley, 2009. • Semiconductor manufacturing technology, Michael Quirk, Julian Serda, 1st ed., Pearson, 2000. • Semiconductor Material and device characterization, Dieter K. Schroder, 3rd ed., Wiley, 2006. • Fundamentals of Device and System Packaging: Technologies and Applications, Rao Tummala, 2nd ed., McGraw-Hill Education, 2019