# Indian Institute of Technology Kanpur

# COURSES OF STUDY

# 2024

**Indian Institute of Technology Kanpur**
**KANPUR-208016**

# PHYSICS

## PHYSICS

| BS | | | | | | | | Template No. BS-PHY-1 |
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| | SEMESTER | | | | | | | |
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th |
| C O U R S E S | MTH101A [11] | MTH102A [11] | PHY224A [12] | SO-1 [08] (PSO201A) | PHY315A [09] | PHY412A [11] | PHY461A [08] | HSS-5 (Level-2) [09] |
| | PHY101A [03] | PHY103A [11] | ESO-1 [~10]* | ESC201A [14] | PHY401A [11] | PHY473A [08] | PHY552A [11] | DE-3 [09]/ UGP-3 [09] (PHY557) |
| | PHY102A [11] | ESC101A [14] | ESO-2 [~10]* | PHY210A [06] | PHY421A [11] | PHY399A [02] | HSS-4 (Level-2) [09] | DE-4 [09] |
| | LIF101A [06] | CHM101A [03] | HSS-2 (Level-1) [11] | PHY226B [06] | PHY431A [11] | HSS-3 (Level-2) [09] | DE-2 [09] | OE-5 [09] |
| | ENG112A/HSS-1 (Level-1) [11] | CHM102A [08] | TA202A [06] | TA201A [06] | ESO-3 [~10]* | DE-1 [09] | OE-3 [09]/ UGP-2 [09] (PHY556A) | OE-6 [09] |
| | PE101A [03] | PE102A [03] | COM200A [05] | OE-1 [09] | - | OE-2 [09] | OE-4 [09] | UGP-4 [09] (PHY558A) (extra credits) |
| | TA101A [09] | - | - | - | | - | UGP-1 [04] (PHY555A) (extra credits) | |
| | 54 | 50 | 54* | 49 | 52* | 48 | 55 | 45 |

**MINIMUM CREDIT REQUIREMENT FOR GRADUATION:**

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| Institute Core (IC) | : | 124 | Credits |
| Department Compulsory (DC) | : | 106 | Credits |
| Department Elective (DE) | : | 36 | Credits |
| Open Elective (OE) | : | 54 | Credits |
| *SO/ ESO | : | 40 | Credits |
| HSS (Level-I) | : | 22 | Credits |
| HSS (Level-II) | : | 27 | Credits |
| Total | : | 409 | Credits |

**REMARKS:**

1) *SO/ESO courses should be selected to ensure that the four courses add up to 40 credits.
2) OE credits may include 09 credits of UGP-2.
3) DE credits may include 09 credits of UGP-3.
4) UGP-1 and UGP-4 are optional and does not count towards DE/OE credits.
5) Upto 36 OE credits may be waived from the minimum requirements for students opting for either Dual Degree or Double Major programme.

| DEPARTMENT OF PHYSICS | | | |
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| **Course ID** | **Course Title** | **Credits L-T-P-D-[C]** | **Content** |
| PHY 111 | PHYSICS LABORATORY | 0-0-3-0 (3) | Introduction to data and error analysis, and plotting; prism spectrometer; velocity of light; Helmholtz coil; coupled pendulum; collision on a linear air track; Pohl's pendulum; Moment of inertia of a bicycle wheel; electromagnetic induction; current balance; gyroscope. |
| PHY 112 | Classical Dynamics | 3-1-0-0 (11) | Mathematical preliminaries: partial derivatives, vector differentiation, matrix eigenvalue problem.<br><br>Review of Newton's laws of motion, transformations and symmetries, inertial versus non-inertial frames, conservative versus non-conservative forces, potentials.<br><br>Newton's law in plane-polar coordinates, application of (momentum, energy, angular momentum) conservation laws: central force problem, collision between point masses in plane, Rutherford scattering. Forced and damped oscillations, resonances.<br><br>Phase space, equilibrium and fixed points, first and second order autonomous systems: linear stability analysis and classification of fixed points, attractors, conservative versus nonconservative systems, quasi periodicity.<br><br>Constrained motion, types of constraints, method of virtual work, Euler—Lagrange equation from d'Alembert's principle.<br><br>Lagrangian, symmetry, cyclic coordinates, conserved quantities, small oscillations in two degree of freedoms ystems.<br><br>System of point masses, angular momentum and torque (for non-fixed axis rotation), moment of |

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| | | | inertia tensor, principal axes, Euler's equations, torque free precession<br>(symmetric top). |
| PHY 113 | Introduction to Electromagnetism | 3-1-0-0 (11) | Vector calculus, Electrostatic with full use of vector calculus calculation of electric fields, Energy in electrostatics<br><br>Electrostatic potential and Laplace's equation and uniqueness of its solution; Method of images<br><br>Introduction to multipole expansion, Dipole moment of a charge distribution, potential and field of a dipole, force and torque on a dipole in an electric field;<br><br>Electrostatics in a medium, Displacement vector and boundary conditions, linear dielectrics, force on a dielectric<br><br>Magnetostatics with full use of vector calculus, introduction to vector potential; current densities, Lorentz force law, force and torque on a magnetic dipole in a magnetic field<br><br>Magnetostatics in a medium, magnetization, bound currents, magnetic field H, boundary condition on B and H, magnetic susceptibility, ferro, para and diamagnetism.<br><br>Faradays law, energy in magnetic field; displacement current; fields produced by time-dependent electric and magnetic fields within quasistatic approximation<br><br>Maxwells equations in vacuum and conducting and nonconducting medium, Energy in electromagnetic field, Poynting vector plane electromagnetic waves; Reflection and refraction of electromagnetic wave from a boundary, Brewsters angle. |
| PHY 114 | Quantum Physics | 3-1-0-0 (11) | Experimental basis of Ouantum Physics<br>Failure of the classical theory: Black body radiation, photoelectric effect, Radioactivity,<br>Compton effect, wave particle duality, de Broglie hypothesis, electron microscope, experiment with photons. Specific heat of solids.<br>Theoretical foundations of Quantum physics<br><br>Postulates of quantum physics and mathematical |

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| | | | background (complex numbers and Fourier analysis). Helmholtz wave equation from optics. The<br>Schrodinger equation and its statistical interpretation. The wave function. Operators in quantum physics. Measurements and Heisenberg’s<br>uncertainty principle.<br><br>Simple examples and applications<br><br>Time independent Schrodinger equation in one dimension and stationary states. Simple examples may include the free particle, the wave packet, the infinite square well, and the step potential.<br><br>Tunnelling and Alpha decay. Quantum rotor.<br>Vibration and rotational energy levels of molecules.<br>More recent applications may include : Laser physics. semiconductors, transistors and solar cells.<br>Nuclear and electron spin and Stern Gerlach experiment. Nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI).<br><br>Basics of quantum computation<br>Linear algebra for two state systems. Qubits, and two<br>level quantum gates. Basics of quantum computation<br>and quantum cryptography |
| PHY115 | Oscillations and Waves | 3-1-0-0 (11) | Examples of oscillations in physics (e.g., solar cycle), chemistry (e.g.,<br>oscillating reactions), biology (e.g., circadian rhythms), ecology (e.g.,<br>predator-prey cycle), economics (e.g., business cycles: Goodwin’s<br>class struggle model), atmospheric science (e.g., weather cycle), etc. 8<br>Simple harmonic motion, effect of damping, effect of external<br>forcing, resonance, examples of resonances (e.g., atmospheric tide,<br>NaCl crystal, swing). |

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| | | | Two coupled simple harmonic oscillators and normal modes (e.g.,<br>atoms in molecules, coupled electrical circuits, coupled pendula).<br><br>Phase oscillators (examples from electronics, condensed matter<br>physics, biology, mechanics), synchronization (e.g., firefly<br>synchronization).<br>Harmonic analysis, superposition, qualitative introduction to<br>nonlinear effects.<br><br>Many coupled particle oscillations and passage to continuum<br>oscillating medium, one dimensional non-dispersive waves, 1st and<br>2nd order wave equations, damping of waves.<br>Longitudinal (e.g., acoustic waves) versus transverse waves (e.g.,<br>electromagnetic waves in vacuum), polarised versus unpolarized<br>waves, energy and momentum of waves.<br>Reflection, refraction, and transmission in one dimensional waves;<br>interference and diffraction.<br><br>Dispersion, phase velocity, group velocity, water waves (gravity and<br>capillary), de Broglie waves, wave packets.<br><br>Qualitative introduction of nonlinear effects |

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| PHY204 / PSO 201 | QUANTUM PHYSICS | 2-1-0-0 (8) | Foundations of quantum mechanics Black body radiation, photoelectric effect, Compton effect, de Broglie hypothesis and its experimental verification 5 lectures Time independent and time dependent Schrodinger equation, Born interpretation, Expectation values, free particle wavefunctions and wave packets, uncertainty principle 5 lectures Solution of stationary state Schrodinger equation for particle in a box, particle in a finite well, reflection and transmission across a step potential, application to phenomena like alpha decay , one dimensional harmonic oscillator 5 lectures Solution of stationary state Schrodinger equation for the ground state of hydrogen, Discussion of excited state, Explanation of the periodic table by introduction of electron spin and Pauli's exclusion principle, Stern-Gerlach experiment, two level systems 5 lectures Free particle wave functions and metals, Kronig Penny model and formation of bands in one dimension 4 lectures Variational principle for approximate solutions and simple applications, ground state energy of helium atom 3 lectures Interaction of light with matter Einstein's phenomenon logical theory, lifetime of a state, LASERS 3 lectures Feynman lectures volume III Max Jammer Conceptual development of quantum mechanics B.L. van der Waerden Sources of quantum mechanics E. Shroedinger Papers on wave mechanics R. Shankar Principles of quantum mechanics |

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| PHY205M | Fundamentals of Soft Matter | 3-1-0-0 (6) | 1 Introduction to soft matter<br>• What is soft condensed matter?<br>• Colloids, polymers, amphiphiles, liquid crystals<br>• Forces, energies, timescales<br><br>2 Brownian motion<br>• Equilibrium fluctuation properties<br>• Diffusion in simple fluids and Stokes' drag<br>• Fluctuation dissipation theorem<br><br>3 Colloids<br>• Colloidal dispersions<br>• Excluded volume, depletion interactions<br>• van der Waals attractions, electrostatics, ions, and DLVO<br>• Tunable colloids, active colloids and applications<br><br>4 Polymers<br>• Structure of maromolucules<br>• Random walks and relaxation dynamics<br>• Viscoelasticity<br><br>5 Surface and interface<br>• Surface tension, interfacial tension and capillary action<br>• Wetting<br>• Adhesion and friction<br>• Slip behavior |
| PHY210M | THERMAL PHYSICS | 3-1-0-0 (6) | Principles of thermodynamics (with applications to simple fluids), applications of thermodynamics: concept of thermodynamic state, extensive and intensive variables; heat and work, internal energy function and the first law of thermodynamics; fundamental relation and equations of state; concepts of entropy and temperature as conjugate pair of variables; second law of thermodynamics, entropy maximum and energy minimum principles; thermodynamic potentials: enthalpy, Helmholtz potential, Gibbs potential; conditions of equilibrium, concepts of stable, metastable and unstable equilibrium; components and phases, Gibbs-Duhem relations; first order phase transitions and Clausius-Clapeyron equation; concepts associated with critical and multicritical phenomena, some chosen applications from surfaces and interfaces, chemical reactions (magnetic, dielectric and superconducting); heat engines and black body radiation; elementary kinetic theory of gases: equilibrium properties |

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| | | | pressure and equation of state; transport processes momentum transport and viscosity, energy transport and thermal conductivity, charge transport & electrical conductivity (without using Boltzmann transport equation);entropy, multiplicity and disorder: entropy measures multiplicity rather than disorder, illustration with simple examples; Maxwell's demon; qualitative justifications of laws of thermodynamics (without introducing ensembles), thermodynamics of irreversible processes: entropy production. |
| PHY224 | OPTICS | 2-0-6-0 (12) | Review of Maxwell's equations, wave equation and solutions for plane and spherical waves Linear dispersion theory. Derivation and discussion of Fresnel's equations Polarization states of polarization, Jones vectors, Jones matrices, index ellipsoid Interference basics, 2 beam, N beam discussion, interferometers Michelson and FabryPerot, multilayers for high and antireflection Diffraction Kirchhoff integral, Fraunhofer diffraction, diffraction grating Coherence spatial, temporal coherence, measurement techniques, mutual coherence function, coherency matrix<br><br>Course Reference: 1.M.Born and E.Wolf, Principles of Optics (Cambridge Univ Press); 2.J. B. Peatross and M. Ware: Physics of Light and OpticsThis book is freely available at http://optics.byu.edu/BYUOpticsBook.pdf; 3.F.L. Pedrotti, L.M. Pedrotti and L.S.Pedrotti: Introduction to Optics (Pearson InternationalEdition); 4.A.Ghatak, Optics (Tata McGrawHill); 5.E.Hecht, Optics (AddisonWesley); 6. K.K.Sharma, Optics: Principles and Applications (Academic Press) |
| PHY226M | RELATIVITY | 3-1-0-0 (6) | Special Relativity: empirical evidence for the constancy of c, frames of reference; 6Lorentz transformations; relativity of simultaneity; twin and other paradoxes; Spacetime diagrams; Transformation laws for velocity, momentum, energy; mass energy equivalence; vectors; Force equations, kinematics of decays and collisions; Maxwell's equations in covariant form. |
| PHY301 | ENERGY | 3-0-0-0 (9) | Indian and global energy resources, current energy exploitation, energy demand, energy planning, renewable energy sources, wind energy, energy from water, solar energy, energy from mineral oils, nuclear energy, energy for |

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| | | | sustainable development, environmental concerns. |
| PHY302 | Introduction to Quantum Materials | 3-0-0-0 (9) | Scales and symmetries in physics, Bird’s eye view of materials around us (3), Brief Review of Quantum Mechanics and Thermal Physics (Equipartition Theorem, Quantum and Classical Distribution Functions) (5)<br><br>Free Electron Gas (Metals, fermi surface, density of states) (3), Thermal and Mechanical Properties of metals and alloys (2), Lattices and Brillouin Zone, Brief Introduction to XRD (3), Electrons in Periodic Potentials, Bloch Theorem and Energy Bands in One Dimension (2), Insulators/semiconductors around us and their band structures, Concept of holes (2)<br><br>Electron Spin and its Magnetic Moment (1), Exchange Energy and Hund’s Rules (2), Dia and Paramagnetism (Larmor, Curie, Pauli) and magnetic response of everyday materials. (4) Introduction to Ferromagnetism (1)<br><br>Drude theory, Lorenz Number, Wiederman-Franz (4), Characteristic Length Scales in Different type of transport mechanism in materials (2)<br><br>Crystal Vibrations Introduction to Normal Modes (1), Acoustic Phonons and Specific Heat (3)<br><br>Introduction to phenomena such as superconductors, electronics and spintronics. |
| PHY303 | PRINCIPLES OF LASERS & THEIR APPLICATIONS | 3-0-0-0 (9) | Gaussian optics, optical resonators and their mode structure, atomic levels, absorption, spontaneous and stimulated emission, Einstein coefficients, rate equations, population inversion, gain media, 3 and 4 level lasers, CW & pulsed lasers, Q-switching, mode locking, short pulses, Ar+, CO2, Nd: YAG, diode lasers, etc.; metrology, optical communication, materials processing, holography, medical applications. |
| PHY305 | PHYSICS OF UNIVERSE | 3-0-0-0 (9) | Astronomical observations and instruments, photometry, stellar spectra and structure; stellar evolution, nucleosynthesis and formation of elements, variable stars, compact stars, star |

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| | | | clusters and binary stars, galaxies, their revolution and origin, active galaxies and quasars, Big Bang model, early Universe and CMBR. |
| PHY307 | MODERN OPTICS | 3-0-0-0 (9) | Review of Maxwell's equations and electromagnetic wave equation, wave propagation in anisotropic media, polarized light, diffraction from circular aperture and concept of resolution, Fourier transforms and Fourier optics, spatial filtering, and image processing, coherence, holography, optical waveguides and integrated optics, optical fibers, optical communication sources (LED, lasers etc.) and detectors, electro and magneto optic effects, laser matter interaction. |
| PHY312 | QUANTUM PROCESSES IN LOW DIMENSIONAL SEMICONDUCTORS | 3-0-0-0 (9) | Characteristic length scales for quantum phenomena; scaling as a heuristic tool; scientific and technological significance of nanostructures and mesoscopic structures. brief introduction to quantum view of bulk solids, introduction to key ideas in transport and interaction of photons with material. Quantum structures: electronic properties: science and technology realizing low dimensional structures; MBE, MOCVD, Langmuir Blodget films, novel processes; electronic properties of hetero structures, quantum wells, quantum wires, quantum dots, and superlattices, strained layer super lattices; transport in mesoscopic structures. resonant tunnelling, hot electrons, conductance and transmission of nanostructures; principles of application of electronic devices. quantum structures: optical properties: optical process in low dimensional semiconductors. absorption. luminescence, excitons. application to lasers and photo detectors, transport in magnetic field: magneto transport: transport in magnetic field, semiclassical description, quantum approach, Aharonov Bohm effect, Shubnikov deHaas effect; introduction to quantum Hall effect. |
| PHY315 | MODERN PHYSICS LABORATORY | 1-0-6-0 (9) | Modern experimental techniques with a view to demonstrate the basic concepts in physics through experiments. this course has three components: a) one lecture per week: observation, measurements, quantification and accuracies in physics, error analysis. experiments that changed classical physics: blackbody radiation, the discovery of electron, quantization of charge, e/m ratios, Millikan's oil drop experiment, Stern Gerlach experiment, Rutherford scattering, Davisson |

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| | | | Germer experiment, discovering atomic nature through optical spectroscopy; production and measurement of high pressure and high vacuum, low and high temperatures; femto seconds to light years. b) laboratory work (twice a week): a current list of experiments is available with the Department. c) small project/open ended experiments: These experiments will be chosen by students after brief library search in consultation with the associated faculty. These, may be carried out in research labs and using central facilities. |
| PHY401 | CLASSICAL MECHANICS I | 3-1-0-0 (11) | 1.) Review of Newton's laws of motion, Galilean transformations, Frames of reference and pseudoforces. Symmetries in Newton's laws, Lagrangian formulation, Configuration space. Calculus of variations, Hamilton's principle of least action, Euler Lagrange's equations, Conserved quantities and Noether's theorem. Small oscillations and normal modes, An harmonic oscillators, Resonances in harmonic and an harmonic oscillaors, Parametric resonance. Secular (regular) perturbation theory, Lindtstedt-Poincare method. Rigid body dynamics. Tutorial problems: One degree of freedom (DOF) and 2) DOF simple harmonic oscillators, Double pendulum, Motion in central force field, System of particles, Charged particle in an Elecromagnetic field, Lagrangian formulation of relativistic mechanics, etc. Fixed points and linear stability analysis, Limit cycles, Flow on a torus and quasi periodicity, Qualitative discussion of Poincare-Bendixon theorem (no chaos in 2D autonomous flow). Legendre transformation, Hamiltonian formulation, Phase plane, Integral invariants, Symplectic area conservation, (Generalized) Liouville's theorem, Poincare recurrence theorem, Modified Hamilton's principle. Canonical transformations, Infinitesimal canonical transformations, Poisson brackets, Active view versus passive view of canonical transformations. Principle of varying action and Hamilton-Jacobi theory, Optico-mechanical analogy, Action-angle variables 3.) Lorenz system, Chaotic attractor, Lyapunov exponents. Qualitative discussion of non-integrability and chaos in Hamiltonian systems.N.B.: The topics in boldface* are essential for Classical Mechanics II.<br>Course Reference: 1. J. V. Jose & E. J. Saletan, Classical Dynamics, Cambridge University Press |

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| | | | (1998); 2. I. C. Percival & D. Richards, Introduction to Dynamics, Cambridge University Press (1982); 3. L. D. Landau & E. M. Lifshitz, Mechanics, Butterworth-Heinemann (1976); 4. H. Goldstein, Classical Mechanics, Addison-Wesley (1 980); 5. J. L. McCauley, Classical Mechanics, Cambridge University Press (1997); 6. I. M. Gelfand & S. V. Fomin, Calculus of Variations, Dover Publications (2000); 7. S. H. Strogatz, Nonlinear Dynamics and Chaos, Westview Press (2001 ). |
| PHY402 | CLASSICAL MECHANICS II | 3-1-0-0 (11) | Review of essential basic concepts of Classical Mechanics I (PHY401), Integrable and super integrable systems, Lax pairs, Bihamiltonian systems, Toda lattice; 1.5 DoF systems: Extended phase space, Rapidly oscillating systems, Adiabatic invariance, Hannay angle, Poincare map, Homoclinic tangle, Melnikov method, Chaos in horseshoe map and symbolic dynamics; 2 DoF systems: Canonical perturbation theory, Problem of small divisors, Area-preserving maps, Poincar & eacute;-Birkhoff theorem, Introduction to KAM theory, Local vs. widespread/global chaos, Chirikov resonance-overlap criterion, Canonical perturbation theory, Problem of small divisors, Area-preserving maps, Poincaré-Birkhoff theorem, Introduction to KAM theory, Local vs. widespread/global chaos, Chirikov resonance-overlap criterion; 2 DoF systems: Geometry of resonances, Overview (no proofs) of Nekhoroshev theorem and Arnold diffusion, Fermi; Ulam-Tsingou problem, Kuramoto model and synchronization; Continuous systems: Lagrangian and Hamiltonian formulations. Recommended<br><br>Course Reference : 1. J. V. Jose & E. J. Saletan, Classical Dynamics, Cambridge University Press (1998); 2. H. Goldstein, C. Poole, & J. Safko, Classical Mechanics, Addison-Wesley (2001); 3. A. Lichtenberg & M. Lieberman, Regular and Chaotic Dynamics, Springer (1992); 4. M. Tabor, Chaos and Integrability in Nonlinear Dynamics, Wiley-Interscience (1974); 5. S. Wiggins, Introduction to Applied Nonlinear Dynamical Systems and Chaos, Springer (2003); 6. A. Goriely, Integrability and Nonintegrability of Dynamical Systems, World Scientific (2001). |

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| PHY404 | Order and Chaos | 3-0-0-0 (9) | 1D and 2D autonomous maps, Conservative vs. dissipative dynamics, Phase space, Cobweb diagram, Stability analysis, Bifurcations (transcritical, flip, Neimark-Sacker etc.), Periodicity, Chaos, Strange attractor, Lyapunov exponents, Routes to chaos, Period doubling, Quasiperiodicity, Intermittency, Feigenbaum's constants: universality and renormalization.<br><br>1D, 2D, and 3D autonomous flows, Conservative vs. Dissipative systems, Poincare section, Bifurcations (saddle-node, transcritical, pitchfork, Hopf, etc.), Lyapunov function, Limit cycles, Perturbation techniques (Lindstedt-Poincare, multiple time scale, renormailzation group, and equivalent linearization), Chaos.<br><br>Fractals, Fat fractals, Multifractal, Fractal Dimensions, Fractal basin boundary, Riddled basins.<br><br>Synchronization, Spatiotemporal chaos, Examples of chaos and fractal from physical sciences, engineering and biology |
| PHY407 | SPECIAL & GENERAL RELATIVITY | 3-0-0-0 (9) | Special Relativity: empirical evidence for the constancy of c, frames of reference; Lorentz transformations; relativity of simultaneity; twin and other paradoxes, transformation laws for velocity, momentum, energy; mass energy equivalence; force equations, kinematics of decays and collisions, Maxwells equations in covariant form, representations of the Lorentz group and SL(2,C).Introduction to General Relativity: principle of equivalence; Machs principle, Riemannian geometry; Christoffel symbols, the curvature and stress energy tensors; the gravitational field equations; geodesics and particle trajectories, Schwarzchild solution; experimental tests, basic cosmology, FRW metric; cosmological expansion; cosmic microwave background; helium abundance; anisotropies in the CMBR. |
| PHY412 | STATISTICAL MECHANICS | 3-1-0-0 (11) | Review of Thermodynamics, Probability theory, Random Walk, Brownian motion, Diffusion Equation, idea of Langevin and Fokker-Planck Equations<br>Basic principles of Equilibrium Classical Statistical Mechanics, Micro-Canonical, Canonical and Grand Canonical ensembles. |

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| | | | Quantum Statistical Mechanics, Density Matrix, Ideal Quantum Gases and their properties, Bose-Einstein Condensation, Free Electron gas.<br>Ising model of Magnetism, Transfer Matrix method, Mean field theory b) Phase Transitions, Curie-Weiss theory, Landau theory, Scaling near a critical point.<br>Course Reference: 1. Reif, Huang, Pathria, Landau and Lifshitz, S. K. Ma, Chaudhury and Stauffer; 2. A.C. Melissiuos and J. Napolitano, Experiments in Modern Physics, znct ed. (Academic Press, Amsterdem, 2003); 3. Resource Files on Experiments maintained in the Laboratory; 4. P. R. Beviugton, Data Reduction and Error Analysis for Physical Sciences (McGraw Hill, 1969). |
| PHY421 | MATHEMATICAL METHODS I | 3-1-0-0 (11) | 1 Vector, Matrix and Tensor Linear vector space: basis, orthogonality and completeness; matrices; determinants, similarity transformations, diagonalization, eigen values and eigen vectors; elementary ideas about tensors<br><br>2 Ordinary differential equations First and second order ODEs, Homogeneous ODEs, Frobenius method, Wronskian, inhomogeneous ODE, Green's functions, Self-adjoint ODE and SturmLiouville theory.<br><br>3 Complex analysis Complex variables, analytic functions and Cauchy-Riemann conditions, Cauchy's Integral theorem, Taylor and Laurent series, poles and branch points, residue theorem, contour integrations<br><br>4 Integral Transforms Fourier series and Fourier transform, Laplace transform, applications of integral transforms to differential and integral equations. |
| PHY431 | QUANTUM MECHANICS I | 3-1-0-0 (11) | Origins of Quantum Theory, Schroedinger Equation, Applicationto One Dimensional Problems, WKB Approximation, Central Potentials, Quantum Harmonic Oscillator, Hydrogen Atom, Hilbert Space Formalism for Quantum Mechanics, Synunetries in Quantum Mechanics, Angular Momentum, Addition of Angular Momenta, Identical Particles, Spin and Statistics, Pauli Exclusion Principle, Variational Method, Applications to Helium Atom and Hydrogen Molecule Ion. |

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| PHY441 | ELECTRONICS | 2-1-3-0 (11) | Review of network theorems and network analysis Operation Amplifier and negative feedback OpAmp limitations and applications Circuits with OpAmps and diodes Interfacing BJT with OpAmps MOSFETs Digital electronics: Gates, flipflops, counters, timers Arduino Uno: Programming with microcontroller and applications.<br><br>Course Reference: 1. The art of electronics; by P. Horowitz and W. Hill; Student Manual for The Art of Electronics; by T. C. Hayes and P. Horowitz; 2. OpAmps and linear integrated circuits; by R.A. Gayakwad; 3. Digital fundamentals; by T. L. Floyd; 4. Digital computer electronics; by A.P. Malvino and J.A. Brown. |
| PHY461 | EXPERIMENTAL PHYSICS I | 0-0-8-0 (8) | Experiments in General Physics, Optics, Nuclear Physics and Condensed Matter Physics (List of current experiments available with the Physics Department in the form of a manual). |
| PHY462 | EXPERIMENTAL PHYSICS II | 0-0-8-0 (8) | Experiments in General Physics, Optics, Nuclear Physics and Condensed Matter Physics (List of current experiments available with the Department in the form of a manual). |
| PHY501 | M SC REVIEW PROJECT II | 0-0-9-0 (9) | Technical review of literature on a topic of interest |
| PHY502 | M.SC. REVIEW PROJECT III | 0-0-9-0 (9) | Technical review of literature on a topic of interest |
| PHY552 | CLASSICAL ELECTRODYNAMICS I | 3-1-0-0 (11) | Basic Laws of Electrodynamics: Maxwell's equations, scalar and vector potentials; Boundary Value Problems: Dirichlet and Neumann Boundary Conditions; Formal Solution of the Poisson Equation Using the Green Function; Method of Images, Construction of the Green Function from Images; Laplace Equation as Boundary Value Problem in electrostatics, applications; Electric Multipole Expansion; Electric polarization; Boundary value problems in magnetostatics; Multipole Magnetic Moments; Generalized Ampere's Law in Material Media; Energy and Momentum Conservation: Poynting Theorem; Electromagnetic waves in vacuum and in dielectric media; Polarization; Stokes parameters, Fresnel equation; electromagnetic wave in conducting media; Multipole radiation: Electric dipole and quadrupole radiation, magnetic dipole radiation, antenna; Long |

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| | | | Wavelength dipole scattering, general formulation and applications;Introduction to waveguides and resonant cavities. |
| PHY555 | BACHLOR OF SCIENCE PROJECT -1 | 0-0-4-0 (4) | A well-defined new problem is to be researched. |
| PHY556 | BACHLOR OF SCIENCE PROJECT - II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY557 | BATCHLOR OF SCIENCE PROJECT - III | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY558 | BATCHLOR OF SCIENCE PROJECT - IV | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY563 | M.SC. PROJECT I | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY565 | M.SC. PROJECT II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY566 | M.SC. PROJECT III | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY568 | M.SC. PROJECT IV | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY596 | M.SC. RESEARCH PROJECT I | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY597 | M.SC. RESEARCH PROJECT II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY598 | M.SC. RESEARCH PROJECT I | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY599 | M.SC.RESEARCH PROJECT II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY606 | Soft Matter: Concepts and Methods | 3-0-0-0 (9) | Review to fundamentals of soft matter<br>• Colloids, polymers, amphiphiles, liquid crystals<br>• Forces, energies, timescales<br>• Brownian motion and related topics<br>• Fluctuation dissipation theorem<br>• Colloidal dispersions<br>• van der Waals attractions, electrostatics, ions, and DLVO<br>• Structure of macromolecules<br>• Viscoelasticity |

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| | | | • Surface tension, interfacial tension and capillary action<br>• Wetting, adhesion and friction<br><br>2. Microscopy Techniques<br>• Bright field, polarization, phase contrast microscopy<br>• Fluorescent and confocal microscopy<br>• Imaging, Image processing and particle tracking<br>3. Rheology<br>• Measuring stress-strain properties<br>• Different measurement geometries<br><br>4 Microrheology<br>• Passive microrheology<br>• Active Microrheology<br><br>5 Optical Micromanipulations<br>• Optical forces at different regimes<br>• Calibration of optical forces<br>• Measuring and applying forces using optical tweezers<br><br>6. Scattering techniques<br>• Dynamic light scattering<br>• Diffusive wave spectroscopy<br>• Small angle X-ray / neutron scattering (SAXS / SANS)<br><br>7 Soft Matter Food Physics (Additional lectures if time permits or in weekends) Physics of foodstuffs and cooking |
| PHY607 | Quantum Many Body Physics | 3-0-0-0 (9) |  Second quantization and coherent states.<br> Functional path-integral<br> Perturbation theory: finite temperature and zero temperature.<br> Order parameters and broken symmetry: mean-field theories and fluctuations.<br> Linear response theory and use of Green's function.<br> Landau theory of Fermi liquids*.<br> Ideas of Luttinger liquid*. |
| PHY611 | NUCLEAR AND PARTICLE PHYSICS | 3-1-0-0 (11) | Nuclear physics: Nuclear force and nuclear models, Nuclear decay, Nuclear reaction kinematics,<br>Scattering and reaction cross section,<br>nuclear reactions (compound nuclear, direct etc.), Breit-Wigner resonance formula, Nuclear fission and fusion. |

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| | | | Particle Physics: Natural Units, Evidence for four fundamental interactions, Leptons and hadrons, Historical introduction to the particle zoo, introduction to cross sections and decay rates, Particle accelerators and detectors, invariance principles and conservation laws of parity, Charge conjugation, Time reversal and CP, CPT theorem, isospin, Strangeness. |
| PHY612 | ATOMIC, MOLECULAR & OPTICAL PHYSICS | 3-1-0-0 (11) | Review of one-electron atoms, Fine structure and Hyperfine structure, Spectral consequences offine structure, Stark and Zeeman shifts<br><br>Transition rates, Dipole approximation, The Einstein coefficients, Selection rules and spectrum of one-electron atoms, Line intensities and life-tme of the excited states, Line shapes and widths, Photoelectric effect<br><br>Atom-light Hamiltonian, Density matrix, Optical Bloch equations, Electromagnetically Induced Trannsparency (EIT) and three-level effects<br><br>Electron- electron interactions, Helium energy levels, Exchange interaction, Thomas-Fermi model, Hartree-Fock method, Coupled angular momentum<br><br>Van der Waals and Covalance Bond, Rotational and Vibrational spectroscopy, Molecular electronicspectra, Experimental probes Raman and Infrared spectroscopy, Selection rules, Molecular symmetries and their consequences<br><br>Atomic Bose-Einstein condensate/Non-linear optics/Nanomaterials/Quantum Dots and quantumWells/Carbon cluster |
| PHY613 | ADVANCED STATISTICAL MECHANICS | 3-0-0-0 (9) | 1. Brief recapitulation of Ising model, symmetry breaking, Landau theory and its applications. [6]<br>2. An introduction to scaling and renormalization group theory. Both real and momentum space renormalization group are to be discussed. [8] |

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| | | | 3. Critical dynamics and different models, nucleation, spinondal decomposition and its applications. [6]<br>4. An introduction to quantum phase transitions and topological systems. [8]<br>Books Recommended:<br>1. Nigel Goldenfeld: Lectures On Phase Transitions And The Renormalization Group<br>2. Chaikin and Lubensky: Principles of condensed matter physics<br>3. Quantum phase transitions: Subir Sachdev |
| PHY614 | Classical Electrodynamics II | 3-0-0-0 (9) | Basics of special relativity, relativistic space-time, 4 vectors; transformation properties of tensors; covariant, contravariant and mixed tensors; transformation of electromagnetic fields; covariant formulation of Maxwell's equations;<br><br>Action principle and Lagrangian formalism; Continuous symmetries and Noether's theorem;Symmetry transformation in electrodynamics; gauge invariance; Lorentz force law and Maxwell's equations from action principle; energy-momentum tensor<br><br>Electromagnetic field produced by arbitrarily moving point charge; LienardWichert potential; Radiation by accelerating point charge; Larmor's formula; radiation from an accelerating charge particle in linear and circular motion; Thomson scattering<br><br>Braking radiation (Bremsstrahlung); Cherenkov radiation<br><br>Abraham Lorentz equation of motion |
| PHY615 | NON-EQULIBRIUM STATISTICAL MECHANICS | 3-0-0-0 (9) | Langevin equation: Application to free Brownian particle; Fokker- Planck equation: Application to Diffusion; Kubo formula, Linear response theory, Fluctuation -Dissipation relations, Mapping onto Schroedinger Equation and application to Brownian particle subjected to harmonic potential; Kramers' theory of activated barrier crossing and decay of metastable states, nucleation.<br><br>Markov processes, classifications of states; application to Random walk and birth- death |

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| | | | processes; master eq for interacting systems, Kinetic Ising model: exact solution in one-dimension and mean-field approximation in higher dimensions, critical slowing down.<br><br>Random excursions, backward master equation and distribution of First-passage times; stochastic calculus and calculus of variations; Path Integrals; Info-theoretic and Path-based stochastic thermodynamics, fluctuation theorems.<br><br>Examples of non-equilibrium steady states (e.g., TASEP) |
| PHY616 | SOFT MATTER PHYSICS | 3-0-0-0 (9) | Introduction to Soft Matter, Forces, energies and timescales in soft matter, Thermodynamic aspects of intermolecular forces, van der Waals force, Hydrophobic and hydrophilic interaction, Interfacial phenomenon; wetting, adhesion and friction, Mechanical properties, Introduction to complex fluids, Fluid flow and hydrodynamic instabilities, Foams and emulsions, Polymers, colloids and Surfactants, Liquid crystals, Self assembly in soft matter, Experimental tools for soft matter.<br>Course Reference : 1. Intermolecular and Surface Forces by Jacob N. Israelachvili (Academic Press, 1998); 2. Soft Condensed Matter by R. A. L. Jones (Oxford University Press, 2002); 3. Principles of Condensed Matter Physics by P. M. Chaikin and T. C. Lubensky (Cambridge University Press, 1995); 4. Hydrodynamic and hydromagnetic stability by S. Chandrashekhar (Oxford University Press, 1981); 5. Structured Fluids by Thomas A. Witten (Oxford University Press, 2004); 6. Structure and Rheology of Complex Fluids by Ronald G. Larson (Oxford University Press, 1999). |
| PHY617 | Computational Physics | 3-0-3-0-(12) | Python, C, C++, Fortran, Matlab, or any other suitable language<br><br>Lagrange, Splines<br><br>Newton-Cotes, Gaussian quadrature, Monte Carlo<br><br>Stability and accuracy issues, Explicit vs. Implicit schemes, Predictor-corrector methods (Euler,<br><br>Runge-Kutta), Multistep methods (Adam- |

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| | | | Bashforth). Stiff equations, Leap-frog and Verletmethods<br><br>Spectral method<br>Diffusion equation, Schrodinger equation. Stiff equations, CFL condition<br>Laplace and Poisson's equations<br>Iterative procedure, Newton's method, Secant Method<br>Solve Ax = b, Eigenvalues and eigenvectors<br><br>Statistics, Monte Carlo methods, Examples from statistical physics and particle physics |
| PHY621 | ELECTRONIC STRUCTURE OF MATERIALS | 3-0-0-0 (9) | One electron model, Born Oppenheimer approximation, Hartree & Hartree Fock approximation, density functional theory, local density approximation, beyond LDA. electrons in periodic solids, Blochs theorem, nearly free electron model, energy bands, Fermi surface, The tight binding method, APW method, OPW method, pseudopotential method, KKR method, LMTO method, the full potential methods. applications to different types of solids; electron in disordered solids, mean field theories, coherent potential approximation, KKRCPA. Applications of KKRCPA, tight binding molecular dynamics, applications toclusters and solids, CarParinello methods and its applications to clusters and amorphous semiconductors, applications of electronic structure methods to materials design. |
| PHY622 | CONDENSED MATTER II | 3-0-0-0 (9) | Introduction to the Electron Liquid – Born-Oppenheimer Approximation, Second quantization.<br><br>Review of the Non-interacting electron gas – Sommerfeld theory of Metals and Bloch band theory.<br><br>Effect of electron-electron interaction – Jellium model, Hartree-Fock theory (exchange and correlation effects); Screening and collective phenomena – Random-Phase Approximation, Plasma Oscillations.<br><br>Fermi liquid theory – Concept of quasiparticles, thermodynamics, Response to perturbations and transport. |

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| | | | Fermi Hubbard Model – Charge and Spin density waves, Metal-insulator transitions, Magnetism<br><br>Electrons in Magnetic fields – Integer Quantum Hall effect<br><br>Superconductivity – Electron-phonon interaction, Cooper problem, BCS theory, Computation of observables, Unconventional superconductivity |
| PHY623 | Condensed Matter Physics | 3-1-0-0 (11) | Drude and Sommerfeld theory of free electrons in metals. Fermi surfaces of electrons. Hall effect, Landau levels, Pauli paramagnetism and Landau diamagnetism.<br><br>Chemical bondings (such as Ionic, Covalent and Van der Waals bonding). Geometry of solids: lattices and unit cells. Crystal planes and X-ray diffractions.<br><br>Reciprocal lattice and Brillouin zones. Bloch theorem. Nearly free electron theory of bands. Tight binding theory of bands. Metal, semiconductors and insulators. Examples in square and hexagonal lattices. Basic idea of Berry curvature of electronic<br>bands.<br><br>Lattice vibrations, optical and acoustic phonons. Specific heat and thermal transport by phonons. Motion of electrons in bands and effective mass of electrons and holes. Carrier conduction in semiconductors (pn junctions). Scattering of electrons in bands and electrical conductivity of metals in Boltzmann theory. Wiedemann-Franz law.<br><br>Quantum oscillations and topology of Fermi surfaces. Dielectric function and Kramers-Kronig relations.<br><br>Exchange interaction and band model of ferromagnetism. Magnetic coupling for localized spins. Anti-ferromagnetism. Hysteresis. Spin-waves (magnonics).<br><br>Phenomena of superconductivity. Phenomenological description based on London's equations. Instability of Fermi surface and Cooper |

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| | | | pairing. BCS theory: Meissner effect and flux quantization. |
| PHY624 | MAGNETISM IN MATERIALS | 3-0-0-0 (9) | Magnetism is a branch of condensed matter physics which is constantly evolving in terms of fundamental new discoveries as well as in terms of possible wide-ranging applications. This course will serve as an introduction to the foundational aspects of magnetism in solids. The course will also aim at providing the students with the requisite understanding of the current major research areas in the field of magnetism. The theoretical content will be supplemented by experimental details, wherever necessary. Course contents: Non-interacting spin systems; Isolated magnetic moments, Spin-orbit interaction and crystal field effects, paramagnetism of localized moments, Itinerant paramagnetism, Landau diamagnetism; Interacting spin systems, Phase transitions and magnetic long range order; Magnetic long range order in local and itinerant spin systems; Quantum magnets; Low energy excitation: spin waves; Heavy Fermion Kondo systems; Magnetism and topology in solids: topological insulators and semimetals with magnetic long range order; Quantum Spin liquids; Magnetic long range order in 2D van der Waals crystals; Spin polarization; Spin Hall effect; Ferromagnetic resonance and spin pumping; Inverse Spin Hall effect. Prerequisites: It will be assumed that the students have already taken an introductory course on solid state physics |
| PHY625 | Mathematical Methods II | 3-0-1-0 (11) | Invitation to symmetries and basics of group theory<br><br>Finite groups and their representations<br>Great orthogonality theorems<br>Lie groups and Lie algebras: generalities.<br><br>SU(2) and SO(3): algebra v/s group, applications; SU(3).<br><br>Group theory in quantum mechanics<br>Roots and Weights, Young Tableaux<br>Introducing PDEs through examples : the wave, diffusion and Laplace equations.<br><br>Classification of PDEs. |

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| | | | Separation of variables method,<br>Eigenfunction expansions approach<br><br>Greens function methods, use of<br>integral transforms.<br><br>Properties of Greens functions :<br>analyticity and causality<br><br>Special topics Non-linear PDEs : KdV<br>equation / Nonlinear Schrodinger<br>equation / solitons<br><br>Conformal mapping Complex Analysis Methods of steepest descent |
| PHY626 | Quantum Mechanics II | 3-1-0-0 (11) | Time-independent perturbation theory:<br>non-degenerate and degenerate<br>perturbation theory,<br>Fine structure of hydrogen atom, Stark<br>effects, Zeeman effect<br><br>Time-dependent perturbation theory:<br>interaction picture, two-state problems,<br>Dyson series, Fermi's Golden rule<br><br>Introduction to Scattering cross-section,<br>Lippman-Schwinger equation, Born<br>approximation<br><br>Optical theoremMethod of partial waves: free spherical waves, plane waves in terms of spherical waves, impact parameter, phase shifts<br><br>Absorption & Induced emission of<br>radiation, electric diploe transition, Landau<br>levels etc.<br><br>Klein-Gordon equation and Dirac<br>equation |
| PHY627 | COMPUTATIONAL SIMULATION METHODS IN PHYSICS | 3-0-0-0 (9) | FORTRAN/C programming, structured programming, errors, numerical analysis, differentiation, integration, solution of differential equations, solution of Schrdinger equation, simulations of planetary motion, oscillatory motion, chaotic motion, molecular dynamics simulation, classical and tight binding molecular dynamics, simulation of Ar, density functional theory, CarParrinello simulation, Monte Carlo |

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| | | | simulation, simulation of Ising model, quantum Monte Carlo simulation, genetic algorithms. |
| PHY628 | Physics of Soft Matter and Fluids | 3-1-0-0 (11) | Introducing soft matter: length, time and energy scales, broad class of soft matter systems, universal properties<br><br>van der Waals Interactions, screening of electrostatic interactions, hydrogen bonding, hydrophobic interactions, hard sphere interactions, depletion interaction, Lennard–Jones interactions<br>Structure factor, radial distribution functions [g(r)] and correlation functions, relation between g(r) with the interaction potential, and other thermodynamic variables<br><br>Disorder-order transitions: freezing, isotropic-nematic, etc.; nucleation and growth, Landau–de Gennes theory and Onsager theory of liquid crystals, glass transition, response functions<br><br>Interface growth, Edward–Wilkinson and Kardar–Parisi–Zhang models, dynamic scaling and universal exponents<br><br>Conservation laws, continuity equation, Navier–Stokes equation, entropy production equation, diffusion, dimensionless parameters, ideas of instabilities and turbulence<br>Surface phenomena: surface and interfacial tension, contact angle and wetting, capillary action and oscillations<br><br>Gaussian polymers, entropic elasticity, emergence of viscoelasticity, constitutive equations; Maxwell model, Voight–Kelvin model and Jeffreys model; linear and nonlinear dynamics: shear thinning, shear thickening, and thixotropy<br><br>Introducing self-propulsion and activity, examples of active fluids/ 10 matter, effective parameters, interactions and entropy production,phase behavior/pattern formation |
| PHY631 | PHYSICS OF SEMICONDUCTOR NANOSTRUCTURES | 3-0-0-0 (9) | Review of condensed matter and semiconductor physics, fabrication of quantum nano structures, quantum structures and band gap engineering. Transport in quantum structures with applications, optical properties and applications, quantum |

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| | | | mechanical effects in magneto transport, frontiers in current research. |
| PHY632 | TRANSPORT IN MESOSCOPIC SYSTEMS | 3-0-0-0 (9) | This is a first course in Mesoscopic Physics. The students should have a background in quantum mechanics at least at the level of PSO201 or Phy431. Some basic understanding of condensed matter physics is also desirable.<br>Tentatively, we plan to discuss the following topics in this course:<br><br>1) Introduction, basic length and the corresponding energy and time scales in metals.<br>2) Drudé model; Diffusion equation and Einstein relation; classical size effects.<br>3) Quantum diffusive transport, weak localization, phase coherence and interference effects in non-superconductive systems<br>4) Classical and quantum ballistic transport, conductance quantization, multi-terminal devices and Landauer-Büttiker formalism.<br>5) Landau levels, edge states, quantum Hall effect (integer and fractional) in 2D electron gas<br>6) Charging effects, Coulomb blockade and quantum dots<br>7) Mesoscopic Superconductivity: Josephson effect, RCSJ model, Bloch oscillations, approach to flux and charge Q-bits. |
| PHY634 | LOW TEMPERATURE PHYSICS | 3-0-0-0 (9) | Production of low temperature; Cryostat Design and Experimental Techniques<br>applied to low temperature; thermometry, specific heat,<br>transport phenomena, thermal, electrical and magnetic properties,<br>superconductivity, application of superconductivity, superfluidity and<br>associated phenomena.<br><br>Textbook: Matter and Methods at Low temperature by Frank Pobell. |
| PHY642 | CONDENSED MATTER PHENOMENA IN LOW DIMENSIONAL MATERIALS | 3-0-0-0 (9) | Fundamental concepts of geometric quantities: Berry curvature, Berry phase, intrinsic orbital magnetic moment. Discrete formulation of Berry phase. Aharonov-Bohm effect. Geometric effects in Bloch bands, Anomalous velocity and connection with the Berry curvature.<br><br>Transport coefficients in condensed matter systems: Semi-classical Boltzamann |

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| | | | transport formulation. Effect of band geometric quantities on equations of motion and non-equilibrium Fermi-Dirac distribution function, calculation of transport coefficients, anomalous Hall conductivity.<br><br>Hall effect: Classical and quantum Hall effects. SdH oscillations. Concept of chiral edge states. Topology of Landau levels.<br><br>Spin-orbit coupled electron/hole systems in semiconductor heterojunctions, various transport properties, anomalous Hall conductivity, beating pattern formation in SdH oscillations.<br><br>Dirac materials: Tight-binding Hamiltonian in honeycomb lattice: Graphene and h-BN materials. symmetry properties, quantum Hall effect in graphene, topological properties of zero-energy states. |
| PHY645 | ELECTROMAGNETIC METAMATERIALS AND PLASMONICS | 3-0-0-0 (9) | 1. Electromagnetic and optical response of materials and introduction to structured composite materials (3 lectures)<br>2. Ideas of homogenization and effective medium theories (4 lectures)<br>3. Design of metamaterials with specified effective material parameters: artificial plasmas, artificial dielectrics, artificial resonant magnetic materials, negative refractive index, structural chirality and bianisotropy. (7 lectures)<br>4. Wave propagation in negative refractive index media, anisotropic media, chiral media and bianisotropic media (4 lectures)<br>5. Computing photonics band structures: transfer matrix method. (6 lectures)<br>6. Surface plasmons, localized surface plasmon resonances (4 lectures)<br>7. Applications of surface plasmons: spectroscopy and sensors (2 lectures)<br>8. Negative refraction and perfect lenses, optical near field imaging (6 lectures)<br>9. Transformation optics and electromagnetic invisibility (4 lectures) |
| PHY647 | Photonic Green Nanotechnology | | Introduction to photonics, nanotechnology and "Green" processes [4]<br>• Issues of natural energy flows, energy management and carbon emissions [4]<br>• Interaction of radiation with materials [5] |

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| | | | • Basic properties of photonic nanomaterials materials [5]<br>• Photo-voltaic systems, solar cells and solar collectors [8]<br>• Nanotechnology for indoor lighting, electric lighting, daylight lighting and smart windows [5]<br>• Photonic Cooling technologies: high reflectivity surfaces, sky-cooling and rooftop cooling [5]<br>• Photonic Nanomaterials for Air quality sensing and cleaning scrubbers [4] |
| PHY651 | INTRODUCTION TO ASTROPHYSICAL FLUIDS | 3-0-0-0 (9) | Qualitative introduction to astrophysical fluids.<br>● Derivation of hydrodynamic fluid equations (Euler equations, Navier-Stokes equations) from kinetic theory of gases.<br><br>● Spherically symmetric flows, flows with rotation (stellar models, meridional circulation etc.).<br><br>● Stratified media (stellar models, planetary atmosphere etc.).<br><br>● Different types of stellar oscillations and waves.<br><br>● Different instabilities: Jeans instability, thermal instability, Kelvin-Helmholtz instability, Rayleigh-Taylor instability.<br><br>● Turbulence in hydrodynamic fluids: phenomenology, structure functions, properties of turbulence in cold molecular clouds.<br><br>● Modelling of space and astrophysical fluids as plasmas: introduction to plasmas, derivation of the equations of Magnetohydrodynamics (MHD), invariants and different properties of MHD, waves, concept of dynamo.<br><br>● Instabilities in magnetofluids, their important in space and astrophysics.<br>● Turbulence in an MHD fluid: basic introduction and its importance in modern research of space science and Astrophysics |
| PHY652 | INTRODUCTION TO CONFORMAL FIELD THEORY | 3-0-0-0 (9) | Renormalisation group flows in QFTs and advent of CFTs, Global Conformal<br>Invariance : CFTs in general dimensions, Representation theory, |

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| | | | Correlation functions, Conformal invariance in 2 dimensions, Virasoro algebra and its many consequences, Operator formalism, Use of complex analysis for 2d CFTs, Operator Product Expansions, Energy- momentum tensor and Virasoro algebra, Minimal Models as Simplest models of 2d CFT, Modular Invariance : 2d CFT on the torus, Partition functions, Cardy formula for entropy, Towards holography, Asymptotic analysis in AdS3 and AdS3/CFT2. |
| PHY654 | Machine learning in particle physics | 3-0-0-0 (9) | Introduction to machine learning (12 lectures): Supervised vs unsupervised learning, Logistic regression, Binary classification, Cost function, Gradient descent, Vectorisation, Support Vector Machine (SVM), Example usage of SVM in particle physics, K-Means Algorithm, Principal Components Analysis, Anomaly detection.<br><br>2. Deep Neural Network (11 lectures): Hidden layer, Activation function, Forward and backward propagation, Hyperparameter Tuning, Regularization and Optimization, TensorFlow, End-to-end deep learning, Autoencoders, Example usage of neural networks in particle physics.<br><br>3. Convolutional Neural Networks (10 lectures): Edge detection, Padding, Pooling, Residual Network (ResNet), Example usage of ResNet in particle physics, Yolo algorithm, Neural style transfer, Generative Models, Graph Neural Networks.<br><br>4. Sequence Models (6 lectures): Recurrent neural network (RNN), Gated recurrent unit, Long short term memory unit, Example usage of RNN in particle physics. |
| PHY655 | Introduction to String Theory | 3-0-0-0 (9) | Introduction [4 lectures] o What ails quantum gravity and why string theory. o String theory: introduction to basic ingredients o The relativistic point particle<br>Quantizing the relativistic string [15 lectures] o Action and symmetries o Covariant quantization of the closed string o Open strings and D-branes o Lightcone gauge and critical dimensions<br><br>Compactification [5 lectures] o KK-reduction in field theory o Compactification for closed strings o T-duality o Open strings |

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| | | | Polyakov Path integrals [6 lectures] o Gauge fixing and ghosts Non-critical strings o Vertex operators<br><br>String Interactions [6 lectures] o S-matrix generalities o Veneziano amplitude o Virasoro-Shapiro amplitude<br><br>A quick look at Superstrings [3 lectures] |
| PHY660 | GENERAL RELATIVITY & COSMOLOGY | 3-0-0-0 (9) | Mach's principle. Riemannian geometry. Energy momentum tensor and Einstein's equations. Schwarzschild metric and singularities of space time. Post Newtonian approximations. spherically symmetric solutions of Einstein equations. Introduction to cosmology. |
| PHY661 | Turbulence in space plasmas | 3-0-0-0 (9) | Generic introduction to turbulent flows: (6 lectures) (i) Definition and possible origin(s) of turbulence, fully developed turbulence, Richardson's cascade, Kolmogorov Phenomenology, universality of turbulence. (2 lectures) (ii) Turbulence in MHD fluids: Iroshnikov-Kraichnan (-3/2) and Marsch (-5/3) phenomenologies. (2 lectures) (iii) Exact relations for hydrodynamic and magnetohydrodynamic turbulence. (2 lectures)<br>Space plasmas and their properties: (3 lectures) (i) A comparative overview of the solar wind, the coronal plasma and the magnetospheric plasmas. (3 lectures)<br>Cascade and universality in space plasma turbulence: (15 lectures) (i) MHD scale energy cascade in solar wind turbulence: spectral approach and exact scaling laws, turbulent heating of the space plasmas. (7 lectures) (ii) Anomalous heating of solar wind: effect of compressibility in the solar wind turbulence. (2 lectures) (iii) Sub-ion scale turbulence in the solar wind: cascade vs dissipation. (2 lectures) (iv) Turbulence in magnetospheric plasmas. (2 lectures) (v) Cascade of helical invariants (cross helicity, magnetic helicity etc.) in space plasmas. (2 lectures)<br>Anisotropy in turbulent space plasmas: (10 lectures) (i) Anisotropy of solar wind turbulence: 2D and slab models, critical balance, global vs local mean magnetic field. (7 lectures) (ii) Analysis of anisotropy for non-stationary solar wind intervals. (3 lectures) |

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| | | | Other topics of space plasma turbulence: (6 lectures) (i) Reconnection and turbulence (2 lectures) (ii) Turbulent mechanism of switchback in the solar wind. (2 lectures) (iii) Stellar dynamos and turbulence (2 lectures) |
| PHY665 | Uncertainty, Information and Classical Dynamics | 3-0-0-0 (9) | Different interpretations of probability, frequentist versus Bayesian, Bayes theorem, reviewing probability theory and random variables, basic concepts of Markov chain and ergodicity<br><br>Shannon entropy and its different interpretations, asymptotic equipartition property, generalized entropies (Rényi, Tsallis, etc.), mutual information, relative entropy, differential entropy, entropy rate or source entropy, maximum entropy distribution, minimum relative entropy distribution, Fisher information, data processing inequality<br><br>Lyapunov exponents, invariant density, strange chaotic attractors and fractal dimension (capacity dimension), information dimension, Rényi dimensions, information loss, topological entropy, Kolmogorov–Sinai (KS) entropy, fluctuations around KS entropy and generalized entropies, Rényi entropies and generalized Lyapunov exponents, ε-entropy and finite size Lyapunov indicator<br><br>Reviewing connection between chaos, statistical mechanics, and thermodynamics; second law of thermodynamics and relative entropy, Boltzmann entropy and Gibbs entropy and their connections with Shannon entropy, Landauer's principle, Maxwell's demon, coarse graining and irreversibility, Jaynes' formalism of statistical mechanics, information geometry (e.g., in vapour-liquid equilibrium).<br>Cramer–Rao bound, frequentist versus Bayesian estimations. |
| PHY670 | Evolutionary Game Dynamics | 3-0-0-0 (9) | (1) Basics of evolution: Examples of evolution in biology, ecology, society, and<br>language; Darwin's theory; Mendel's Laws, Hardy–Weinberg principle; Wright's equation for adaptive landscape; |

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| | | | Fisher's fundamental theorem; Price equation; Hamilton's inclusive fitness theory. (2) Basics of game theoretic concepts: Normal and extensive forms; dominant strategy equilibrium, Nash equilibrium, and evolutionary stable strategy; repeated games and evolution of cooperation. (3) Games in infinite population (deterministic models): Quasispecies equation; replicator-mutator equation; evolutionary stable state and its relation to the fixed points; evolutionary stable set; Folk theorem of evolutionary game theory; Bishop–Cannings theorem; connection between replicator-mutator equation and expanded Price equation; doubly symmetric matrix game and Fisher's fundamental theorem; examples like generalized rock-paper-scissors game, language evolution, etc.; mention of other game dynamics (imitation dynamics, monotone selection dynamics, best-response dynamics, adjustment dynamics, logit dynamics, adaptive dynamics, etc.).<br>(4) Games in finite population (stochastic models): Fixation probability of alleles in Wright–Fisher model and Moran model, Kimura's neutral theory of evolution, Diffusion approximation (Kolmogorov forward and backward equations), games in finite population, one-third law and its relation with risk dominance, evolutionary stability, evolutionary graph theory, spatial games, deriving replicator equation from modified Moran model.<br><br>Selected Reference Books: M. A. Nowak, *Evolutionary Dynamics*, The Belknap Press of Harvard University Press (2006); S. H. Rice, *Evolutionary Theory,* Oxford University Press (2004); J. Hofbauer and K. Sigmund, *Evolutionary Games and Population Dynamics,* Cambridge University Press (1998); J. Maynard Smith, *Evolution and the Theory of Games*, Cambridge University Press (1982); D. Friedman and B. Sinervo, *Evolutionary Games in Natural, Social,* |

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| | | | *and Virtual Worlds*, Oxford University Press (2016); R. McElreath and R. Boyd, *Mathematical Models of Social Evolution: A Guide for the Perplexed*, The University of Chicago Press (2007). |
| PHY671 | Femtosecond Magnetism and Terahertz Spintronics | 3-0-0-0 (9) | • Magnetism: Basics of Ferromagnetism, Orbital and Spin angular momentum, spin-orbit coupling, Density of states of the ferromagnetic materials, Soft and hard magnetic materials, Magnetic anisotropies, Magnetometry. (4 Lectures)<br>• Light-matter interaction in ferromagnets: Laser-driven ultrafast demagnetization, different timescales of laser-induced demagnetization process, hot electrons and spins, electron-electron interaction, electron-phonon interaction. (6 Lectures)<br>• Pump-probe measurement technique: Optical Rectification. Free-space Electro-optic Sampling, Ultrabroadband Terahertz Pulses (3 Lectures)<br>• Ultrafast magnetization dynamics: Magneto-optic Kerr effect (MOKE), Pump-probe measurement setup for time-resolved MOKE, Ultrafast magnetization dynamics, Estimation of damping factor, and magnetization relaxation time. (8 Lectures)<br>• Spin transport: Spin injection, spin to charge conversion, Spin Hall effect, Inverse spin Hall effect. Origin of spin to charge interconversion (6 Lectures)<br>• Superdiffusive spin transport: Intense laser field driven differential scattering processes in the magnetic materials, Thermalization, Three temperature model, Ultrafast spin injection and spin relaxation, the co-relation between demagnetization and ultrafast spin-dependent transport. (8 Lectures)<br>• Spintronic Terahertz sources and applications: Time domain spectroscopy, Spintronics terahertz emitters using collinear and non-colinear magnetic systems, Spin-based THz modulators, Ultrafast magnetometer, All-Optical switching of magnetic domains. (5 Lectures)<br><br>Recommended books:<br>• Introduction to Ultrafast Phenomena by Guo-ping Zhang, Georgios Lefkidis, Mitsuko Murakami, Wolfgang Hübner, Thomas F. George<br>• Terahertz Physics by R. A. Lewis, |

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| | | | • Ultrafast Spin Dynamics in Ferromagnetic Nickel, E. Beaurepaire, J.-C. Merle, A. Daunois, and J.-Y. Bigot, Phys. Rev. Lett. 76, 4250 (1996).<br>• Superdiffusive spin transport as a mechanism of ultrafast demagnetization Battiato, M., Carva, K. & Oppeneer, P. M.. Phys. Rev. Lett. 105, 027203 (2010).<br>• Terahertz spin current pulses controlled by magnetic heterostructures Kampfrath, T. et al.. Nature Nanotech. 8, 256–260 (2013).<br>• Prespective: Ultrafast magnetism and THz spintronics, J Walowski and M Munzenberg Journal of Applied Physics, 120, 140901, (2016). |
| PHY672 | PHYSICS OF TURBULENCE | 3-0-0-0 (9) | Review of Navier-Stokes equations, Spectral descriptions, Homogeneity and isotropy in turbulence, Kolmogorov's theory of turbulence, Two-dimensional turbulence, Higher-order structure functions and intermittency, Application of renormalization groups to turbulence and renormalized (eddy) viscosity. Large-eddy simulations. Magnetohydrodynamic Turbulence, Magnetic field generation in turbulent flows (Dynamo), Liquid metal flows, Astrophysical applications, Buoyancy driven turbulence, Rotating turbulence, Instabilities and pattern formation Direct numerical simulation of turbulence. Hands on experience with some of the codes |
| PHY675 | Novel Phases of Quantum Matter | 3-0-0-0 (9) | Topological phases of matter: Free fermionic models and symmetry classification (2). Integer Quantum Hall effect (2). Graphene. Haldane Model. Kane-Mele Model (2) . BHZ Model. Three Dimensional Topological Insulators(2). Bipartite entanglement Entropy (2). Topological invariants and physical observables (2)<br><br>One Dimensional Systems: Jordan Wigner Transformation. Transverse Field Ising Chain (2). Haldane Chain. Su-Schrieffer-Heeger Chain (3). Lieb-Shultz-Mattis theorem (1). Boundary theories (2).<br><br>Topologically Ordered Phases: Fractional Quantum Hall Effect (3). Toric Code (2). Kitaev's honeycomb spin model(2). Topological Entanglement Entropy (1). Quantum Spin Liquids (2). Chern Simons theories and Gauge theories (3). Further special topics (1). |

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| | | | Experimental Overview: Graphene (2), frustrated spin systems (4) |
| PHY 676 | Quantum Technology | 3-0-0-0 (9) | Introduction to quantum technologies - why do we need quantum technologies and its application to understand experimental results - Various platform for implementing Quantum Technology & design robust quantum devices<br><br>Fundamental understanding of Quantum Behaviour - Quantum mechanics, entanglement, superposition, decoherence in open quantum systems, quantum information, quantum noise and quantum error correction theory<br><br>Understanding engineering challenge of present developers and implementation on various sub-domain - Quantum limited sensing - Quantum non-destructive measurement and Metrology - Quantum communication - Macroscopic quantum systems, - Quantum optics, cold atoms and ions - Quantum microwaves - Quantum materials<br><br>Scientific limitation of quantum algorithms and simulation of physics and optimization-atoms and ions- case studies with few literature |
| PHY677 | Optical Imaging | 3-0-0-0 (9) | Review: Review of electromagnetic wave propagation, Fourier transforms<br>Foundations: Wave optics, Diffraction, Eikonal approximation, Basic imaging optics: lenses, telescopes, microscopes, Aberrations.<br>Imaging systems: Field and intensity propagation through a lens, systems of lenses, transfer functions, spatial bandwidth and resolution, coherent and incoherent beam propagation through a lens and a 4 f system, 3d point spread and transfer functions, depth of field.<br>Imaging with transmitted and reflected light: Illumination and detection configurations, Coherent and incoherent illumination, Pupil function engineering, Phase Imaging, Holographic Imaging<br>Fluorescence microscopy: Widefield microscopy, Confocal microscopy, Optical sectioning, Two-photon and multiphoton imaging, Superresolution via PSF engineering and structured illumination, Superresolution via localization and stimulated emission depletion. |

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| | | | Special topics: Quantum enhanced techniques, Nonlinear microscopy, Imaging in scattering media and Ptychography. |
| PHY 678 | Nanomagnetism, Spintronics, and Applications | 3-0-0-0(9) | • Review of Magnetism: Microscopic origin of magnetism, and Fundamental interactions. (3 Lectures)<br><br>• Nanomagnetism and magnetic recording: Magnetic anisotropies, shape and size effect of the magnetic properties of ferromagnets. Super-paramagnetism, Interface magnetism, Magnetism at surfaces and interfaces, Recording media, Magnetic tapes, longitudinal and perpendicular magnetic recording, Heat assisted magnetic recording, Microwave assisted magnetic recording, Heated dot magnetic recording. (8 Lectures)<br><br>• Spin-dependent transport in magnetic materials: Magnetoresistance (GMR,TMR, and AMR), Spin-dependent tunneling, Spin filtering, Spin Valve, Magnetic tunnel junction (MTJ). Concept of spin injection, Magnetic domains,magnetic domain wall propagation. (8 Lectures)<br><br>• Spin dynamics and spin waves: Magnetization dynamics, Landau–Lifshitz–Gilbert equation, ferromagnetic resonance, dynamic exchange interactions.Magnetostatic waves, Magnons, Magnon-Magnon interaction, Spin waves,Spin wave majority logic devices, Directional coupler, Microwave Isolators,Spin-interference for non-Boolean computing. (8 Lectures)<br><br>• Electrical detection of spin current: Spin current to charge current and charge current to spin current conversion, Spin rectification, Landau-Lifshitz Gilbert-Slonczewski (LLGS) equation, Spin torque ferromagnetic resonance, spinPumping-Inverse spin Hall effect, non-local spin valves. (8 Lectures)<br><br>• Application of spintronics: Magnetic Random-Access memory (MRAM), Spin transistor, Spin transfer torque and spin orbit torque driven magnetization switching, Spin torque and Hall nano oscillators, Spin caloritronic devices (Spin Seebeck effect). (5 Lectures)<br><br>Recommended books: |

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| | | | • Introduction to Magnetic Materials, B. D. Cullity and C. D. Graham<br>• Physics of Ferromagnetism, Soshin Chikazumi<br>• Developments in Data Storage: Materials Perspective, S. N. Piramanayagam, Tow C. Chong<br>• Nanomagnetism and Spintronics, Teruya Shinjo<br>• Introduction to Spintronics, S. Bandyopadhyay and M. Cahay<br>• Spin Current, Sadamichi Maekawa, Sergio O. Valenzuela, Eiji Saitoh, Takashi Kimura |
| PHY680 | PARTICLE PHYSICS | 3-0-0-0 (9) | Natural units; evidence for 4 fundamental interactions, leptons and hadrons, historical introduction to particle zoo, relativistic kinematics, Lorentz invariant phase space, calculation of 2 and 3body phase space, Dalitz plot, Mandel stam variables, crossing symmetry, isospin, flavour SU(2), strangeness & flavour SU(3), product representations and Young table aux, the Gell-Mann eightfold way, prediction of quark model, construction of hadronic wave functions, magnetic moment of the neutron, statistics of baryons & concept of colour; discovery of weak interactions, Fermi theory. IVB hypothesis, parity violation, mass problem, and decay; gauge theory, local U (1) gauge theory andMaxwell equations, Yang-Mills theories, SU (2) and SU (3) gauge theories, construction of SU (2) x U (1) gauge theory, gauge boson self interactions, spontaneous breaking of gauge symmetry, Abelian and nonAbelian cases, Goldstone theorem, Higgs mechanism, Ginzburg Landau theory, construction of the Glashow Salam Weinberg model (outline only). |
| PHY681 | QUANTUM FIELD THEORY | 3-0-0-0 (9) | Lorentz and Poincare groups; relativistic wave equations; Lagrangian formalism for fields; symmetry transformations and Noethers theorem; quantization of fields; divergences and renormalization; Yang Mills fields, spontaneous breakdown of symmetries and Goldstone theorem; Higgs phenomenon; unified models of fundamental interactions. |
| PHY682 | CONCEPTS OF PLASMA PHYSICS | 3-0-0-0 (9) | This course has been broadly divided into eight chapters. [1]. Introduction [2]. Charged particle motion in electromagnetic fields [3]. Some basic plasma phenomena [4]. Collisional processes in plasmas [5]. Fluid description of plasmas [6]. |

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| | | | Diffusion and mobility [7]. Equilibrium and instabilities [8]. Introduction to waves in plasmas. |
| PHY683 | Techniques in Experimental High Energy Physics | 3-0-0-0 (9) | Review of the special theory of relativity, choice of units, classifications of particles, the concept of fixed target and collider experiments, neutrino physics, neutrino Oscillations, two-flavor approximation, different types of neutrino interactions, concepts of neutrino oscillation measurement experiment<br>Interaction of radiation with matter(focuses on building detector technology), energy loss mechanism, Bethe-Bolch formula, energy loss mechanism for charged particles, photons, and neutrons, general ideas for designing various types of particle detectors, and working principles of the detectors, Cherenkov detectors, scintillators, gaseous and semiconductor detectors, Calorimeters, spectrometers, Time Projection Chambers, Position and time measurement in detectors, Liquid Argon Technology for high precision particle interaction measurements<br><br>Statistics and Data Analysis Techniques: Basic ideas of probability, random variable, probability distribution, statistical test, significance and power, the goodness of fit, estimators - likelihood, $\chi$ 2 method, the idea of maximum likelihood, confidence interval, incorporation of systematic effects and statistical error in data analysis, propagation of errors, general philosophy of Frequentist and Bayesian interpretation, ROOT software, construction of root tree structure for storing and reading the data |
| PHY690 | SPECIAL TOPICS IN PHYSICS | 3-0-0-0 (9) | The course will deal with specialized topics of current interest in physics. Detailed contents will be given by the instructor when the course is announced. If the number of students is less than 5, this may be floated as a Reading Course with the permission of DPGC. Every new course, other than Reading Courses, offered is numbered PHY 690A, PHY 690B, and so on, until PHY 690Z is reached. After that the cycle repeats from PHY 690A onwards. After been offered once, the course should run in later semesters only with an approved regular non-690 number. |

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| PHY690G | Coherence and Quantum Entanglement | 3-0-0-0 (9) | Introduction, Spectral properties of stationary random processes, Wiener-Khintchine theory, Angular spectrum representation of wavefields, Correlation functions in classical optics<br><br>Introduction to the second-order coherence theory: temporal, spatial, angular and polarization. Propagation of coherence, The van CittertZernike theorem, Coherent mode representation of sources and fields<br><br>Review of quantum mechanics, quantum mechanical correlation function, EPR paradox, hidden variable interpretation of quantum mechanics, Bell inequalities<br><br>Basics of nonlinear optics, entangled two-photon states produced by parametric down-conversion. Two-photon coherence and interference effects, entanglement verification and quantification<br><br>Introduction to Quantum Information: Quantum Cryptography, Quantum Dense Coding, Quantum Teleportation, Quantum Imaging |
| PHY690V | Photonic Devices | 3-0-0-0 (9) | Light-matter interaction – a review Maxwell's equations, wave equation, dispersion in dielectrics, interference and diffraction<br><br>Periodic structures as optical devices Optical multi-layers, diffraction gratings, photonic crystals<br><br>Fiber optic devices Modal theory, devices for wavelength-, direction- and polarization-selectivity, Bragg gratings<br><br>Integrated-optic devices Coupled-mode theory, waveguides and couplers in silicon platform<br><br>Light source Semiconductor laser physics<br><br>Electro-optic and optoelectronic devices Modulators, photodetectors and solar cells<br><br>Novel devices Plasmonic sensors, slow light devices<br><br>Device characterization Measurement techniques related to time- and spectral-domain |

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| PHY692 | MEASUREMENT TECHNIQUES | 3-0-3-0-12 | Typical experiments in various areas is physics; vacuum techniques; transducers: temperature, pressure, charge particles, photons, etc; electronic noise; survey of analog and digital I/Cs; signal processing, data acquisition and control systems; data analysis evaluation. |
| PHY696 | M.SC. RESEARCH PROJECT I | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY697 | M.SC. RESEARCH PROJECT II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY698 | M.SC. RESEARCH PROJECT I | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY699 | M.SC.RESEARCH PROJECT II | 0-0-0-9 (9) | A well-defined new problem is to be researched. |
| PHY701 | Physics Seminar Course-I | 0 Credits | 1. Physics Colloquium – Lectures 5/6 per semesters<br>2. Seminar presentation – Lecture 1 per student per semester |
| PHY 702 | Physics Seminar Course-II | 0 Credits | 1. Physics Colloquium – Lectures 5/6 per semesters<br>2. Seminar presentation – Lecture 1 per student per semester |
| PHY781 | HIGH ENERGY PHYSICS II | 3-0-0-0 (9) | Current topics in Particle Physics and quantum field theory. |
| PHY799 | RESEARCH | | To be registered by PhD. students from Semester I itself, and by M.ScPh.D.(DualDegree) students from Semester V onwards. |
| PHY888 | Introduction to Profession and Communication Skills for Physicists | 3-0-0-0 (9) | Introduction to the profession; Nature and philosophy of physics; Knowing the audience and their needs;<br><br>Identifying the key Point; Putting the work in context – Introduction and literature survey; Designing the writing flow; Developing a good paragraph; Common types of arguments; Importance of the title and abstract.<br><br>Importance of academic integrity; What is plagiarism and self-plagiarism; Responsibilities of Authors and their rights; |

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| | | | Forms and standards; Aids to check and avoid plagiarism; Primacy of credit in the scientific community.<br><br>Summarized views of the various research activities within the department; talks by representative faculty members focussing on the current trends in their respective fields.<br><br>Academia; R&D labs in private and government firms; Interdisciplinarity; Changing track; Start up |
| IDC600M | Introduction to High Performance Computing for scientists and engineers | 3-0-0-0 (5) | About the course: This is an introductory course on parallel programming on scientific applications that will enable the students to write and analyse parallel programs. The focus would be on general parallel programming tools, specially MPI and OpenMP programming. These tools would useful to all students irrespective of their branch. We expect the specific departments or group of departments to teach more advanced courses like Parallel Computational Fluid Dynamics, Parallel Molecular Dynamics, etc. The proposed course would enable the students to take advanced courses on parallel computing. Participating Departments for floating the course: Physics, Chemistry, Biological Science and Bio-Engineering, Aerospace engineering, Mechanical Engineering, Chemical Engineering, Computer Science and Engineering Departments from which students can take course for credit: Physics, Chemistry, Biological Science and BioEngineering, Aerospace engineering, Mechanical Engineering, Chemical Engineering, Computer Science and Engineering |
| IDC601 | Nonlinear Systems and Dynamics | 3-0-0-0 (9) | Dynamics in state space; Description of one and two dimensions using differential equations;<br>No intersection theorem, Fixed Points, Linear instability analysis, Limit Cycle, Poincare-Bendixon theorem, Index theory, Stable and unstable Manifolds. Three-dimensional state space dynamics, Limit cycles and Poincare section, Maps, Chaos. Numerical solution of differential equations. Bifurcation theory, Structural stability; Bifurcation in maps.<br>Period doubling route to chaos; Logistic map, Universality; Intermittency Route to Chaos;<br>Quasi-periodic Route to Chaos: Quasi-periodicity, Frequency locking, Circle map, Devil |

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| | | | staircase;<br><br>Hamiltonian chaos; Integrable and nonintegrable systems; Kolmogorov–Arnold–Moser (KAM) theorem; Standard map;<br><br>Global chaos; Homoclinic and heteroclinic intersection.<br>Fractals; Various definitions of attractor dimension. Connection to Extended systems. Intro<br>to time series analysis. |
| IDC605 | Computational Science and Engineering | 3-0-0-0 (9) | 1. About Computers [2 lecture]<br>2. Programming language (Python, C, C++, Fortran, Matlab, or any other suitable language) [8 lectures]<br>3. Error analysis [1 lecture]<br>4. Interpolation (Lagrange, Splines) [3 lectures]<br>5. Numerical Integration (Newton-Cotes, Gaussian quadrature, Monte Carlo) [4 lectures]<br>6. Numerical Differentiation [2 lectures]<br>7. ODE (ordinary differential equation) solvers: Stability and accuracy issues, Explicit vs. Implicit schemes, Predictor-corrector methods (Euler, Runge-Kutta), Multistep methods (Adam-Bashforth).<br>Stiff equations, Leap-frog and Verlet methods [4 lectures]<br>8. Fourier transform [1 lecture]<br>9. PDE (partial differential equation) solvers: Spectral method [2 lectures]<br>10. Finite-difference method to solve parabolic equations: Examples—Diffusion equation, Navier-Stokes<br>equation. Stiff equations, CFL condition [5 lectures]<br>11. Finite-difference method to solve elliptic equations: Examples—Laplace and Poisson's equations [2<br>lecture]<br>12. Nonlinear equations — Iterative procedure, Newton's method, Secant method [1 lecture]<br>13. Boundary-value problem, Eigenvalue problem [2 lectures]<br>14. Linear algebra: Solve Ax = b, Eigenvalues and eigenvectors, QR method [3 lectures]<br>15. Introduction to Advanced computing and summary [1 lecture] |

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<td>IDC 606A</td>
<td>High Performance Computing with Applications</td>
<td>3-0-0-0 (9)</td>
<td>1. Importance of HPC in current times [1 lecture]<br>2. Introduction to HPC hardware: Top-end CPUs and Memory; HPC clusters: Distributed and shared<br>memory architecture; Interconnect; Accelerators—GPUs; Computer taxonomy, e.g., single instruction<br>multiple data (SIMD) [5 lectures]<br>3. HPC programming paradigms: Single program multiple data (SPMD) & MPMD. [2 lectures]<br>4. Overview of major scientific and engineering applications: Computational Fluid Dynamics; Monte Carlo<br>methods; Structural mechanics; etc. [2 lecture]<br>5. Speeding up C/Fortran/Python programs: Vectorization; Compiler options [2 lectures]<br>6. Programming in Message Passing Interface (MPI): Point-to-point and collective communications; Parallel<br>I/O; MPI for Python and C/Fortran [8 lectures]<br>7. Programming in OpenMP: [4 lectures]<br>8. Introduction to GPUs: SIMD architecture; Case study of Nvidia GPUs [3 lecture]<br>9. Programming GPUs using OpenACC [3 lectures]<br>10. Programming GPUs using CuPy and CUDA [4 lectures]<br>11. Handling big data; Introduction to HDF5 and similar formats [2 lectures]<br>12. Visualisation tools such as Visit and Paraview [2 lectures]<br>13. Case study of several major application [2 lectures]</td>
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<td>PHY643</td>
<td>Coherence and Quantum Entanglement</td>
<td>3-0-0-0 (9)</td>
<td><u>Objectives</u>: This course is for PhD and advanced undergraduate students who want to gain a solid understanding of the concept of coherence as well as its applications in modern quantum optics. The course will have two main parts. The first part will discuss the concept of coherence; the remaining part of the course will focus on Quantum Entanglement.<br><br>Contents:
<table>
<tr><th>S N</th><th>Broad Title</th><th>Topics</th><th>No. of Lectures</th></tr>
<tr><td>1</td><td>Introduction</td><td>Introduction, Spectral properties of stationary random processes,</td><td>8</td></tr>
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| | | Wiener-Khintchine theory, Angular spectrum representation of wavefields, Correlation functions in classical optics | |
| 2 | Classical | Introduction to the second-order coherence theory: temporal, spatial, angular and polarization. Propagation of coherence, The van Cittert-Zernike theorem, Coherent mode representation of sources and fields | 8 |
| 3 | Correlation | Review of quantum mechanics, quantum mechanical correlation function, EPR paradox, hidden variable interpretation of quantum mechanics, Bell inequalities. | 8 |
| 4 | Quantum correlations | Basics of nonlinear optics entangled two-photon states produced by parametric down-conversion. Two-photon coherence and interference effects, entanglement verification and quantification | 8 |
| 5 | Two-photon coherence and entanglement | Introduction to Quantum Information: Quantum Cryptography, | 8 |
| Total number of lectures: | | | 40 |

Pre-requisites: Basic quantum mechanics and optics courses.

Short summary for including in the Courses of Study Booklet: Spectral properties of stationary random processes, introduction to the second-order coherence theory, propagation of coherence,

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| | | | coherent mode representation of sources and fields, basics of nonlinear optics, two-photon field produced by parametric down conversion, EPR paradox, Bell inequalities and its experimental violations, quantum theory of higher-order correlations, two-photon coherence and interference effects, two-photon entanglement, introduction to quantum information, and applications of quantum entanglement such as quantum cryptography, quantum teleportation, quantum imaging.<br><br><u>Recommended books:</u><br>• L. Mandel and E. Wolf, Optical Coherence and Quantum Optics (Cambridge university press, New York, 1995).<br>• R. W. Boyd, Nonlinear Optics, 3rd ed. (Academic Press, New York, 2008).<br>• J. W. Goodman, Statistical Optics, (John Wiley and Sons, 2000)<br>• R. Loudon, The Quantum Theory of Light, 3rd ed. (Oxford University Press, New York, USA, 2000). (v)M. Born and E. Wolf, Principles of Optics, 7th expanded ed. (Cambridge University Press, Cambridge, 1999). |
| PHY656 | Coherence and Quantum Entanglement | 3-0-0-0 (9) | <u>Objectives</u>: This PG level elective course will attempt to summarize the vast field of superconductivity and its applications. It will discuss different aspects of superconductivity from both theoretical and experimental point of view. I will discuss seminal experiments associated with this phenomenon which led to its advancement. The initial part of the course will discuss classical aspects of superconductors, followed by a study of their thermodynamic and magnetic properties and electrodynamic response. An overview of the diverse and modern (emerging) aspects of superconductors along with discussion of new aspects related to phenomena of superconductivity in new emerging materials in the field, devices applications, will be discussed. The course will discuss the BCS theory and develop the gap equation near Tc and discuss various thermodynamic quantities within the purview of the microscopic theory. Ginzburg Landau theory for superconductivity, Abrikosov vortex state, pinning and vortex phases and phase transition in these phases, current voltage |

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relationship of a type Il superconductor in the presence of a magnetic field. Study of tunneling phenomenon in N-I-S or S-I-S junctions, associated Andreev reflection issues, Josephson effect junctions and their applications (SQUID), Superconductivity and vortex physics at nanoscales and device applications and experiments related to superconductivity will be introduced and discussed throughout the course at relevant points in the course. Attempts wherever possible will be made to connect some of the physics with that of superfluidity. The course will also attempt to review some of the latest developments in superconductivity and its applications.
<br><br>
<u>Contents</u>:
<br><br>
<table>
<tr><th>S. No.</th><th>Broad Title</th><th>Topics</th><th>No. of Lectures</th></tr>
<tr><td>1.</td><td>Generation of low and ultra-low Temperatures</td><td>General overview and introduction to thermodynamic principles related to generation of low temperatures. Discussion of Joule Thomson effect, concept of Inversion Temperature, Liquefaction of Helium, Dilution Refrigerator Principles to reach milli kelvin temperatures and ADR technique together with dilution techniques to reach down to microkelvin temperatures. Discussion of temperature measurement techniques using a variety of quantum phenomena.</td><td>4</td></tr>
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| | | | 2. | Overview of Electrodynamics of Superconductors | London's equation and the Meissner response in superconductors, Perfect Diamagnetism and related experimental signatures. Superconducting Penetration depth (R). Electrodynamic Response of Superconductors (AC / DC response and high frequency response (dissipation) — Discussion of Applications). Complex Conductivity and Two fluid Model. Type I SC and Intermediate State (for different geometries). Critical Current density in SC. Distinguishing the Superconducting Response from that of an Ideal (Prefect) Metal response. Discussion of experimental techniques used to measure the magnetization response of superconductors like VSM, Torque sensing, Pickup coil techniques, Micro-hall bar arrays and Scanning Hall. Superconducting materials both classical and modern, high temperature superconductors, Pnictide superconductors, topological superconductors. | 6 |

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| | | | 3. | Thermodynamic Response of Superconductors | Exploring the Thermodynamics aspects of Superconductors in Zero field and in finite applied field. Tc as a phase transition. Order of the SC phase transition in zero and applied magnetic field. Type I and Type Il superconductors, Concepts of Critical Fields. Thermal Conductivity of Superconductors. Discussion of some important Experiments Related to the thermodynamic response of superconductors. Evidence of Energy Gap in DOS. | 5 |
| | | | 4. | Origins of BCS theory and Tunnelling phenomena related to superconductors | Ultrasonic attenuation experiment and evidence of presence of gap in DOS. Measurements of Surface Resistance and concept of Kinetic Inductance and relation of Penetration depth. Isotope Effect. Pedagogic introduction to BSC theory of Superconductivity, Cooper Pairs, Origin of Attractive Interaction. Second quantized formulation of the BCS Hamiltonian, the BCS trial wavefunction. Cooper Pair occupation Probabilities, Evaluation of the Ground State energy. Calculation of Excited | 9 |

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| | | | | | State energy and Energy Gap, DOS, Temperature Dependence of Gap, Tc relation to the gap. Concept of Coherence length C). Tunnelling experiments, Normal — Normal tunnelling, Normal-Insulator-Superconductor Tunnelling. Brief discussion of Andreev Reflections. | |
| | | | 5. | Ginzburg Landau Theory of Superconductivity | Phase coherence in superconductors and the concept of an Order parameter for SC. Discussion of the Ginzburg Landau (GL) free energy formalism and its application to SC, the two differential equations arising from minimizing the GL free energy and the emergence of and <GI. Proximity effect (N-SC boundary and GL solution around it). Type Il superconductivity, Flux Quantization Phenomena, Experiment which led to evidence of flux quantization, Discussion of the Vortex Structure in Type Il superconductor, Linearlized GL equation, Abrikosov vortex state, dependence of Ha and Ha on XGL and their temperature dependence. Vortex state phenomena, | 8 |

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| | | applications, effect current on vortices and dissipation in SC. Vortex Dynamics, Nanostructured superconductors. | |
| 6. | Josephson Effect, Junctions and Applications | Superconducting Phase and Josephson Tunnelling, The Josephson Critical current and Josephson Relations. Short one-dimensional Weak links and the Nature of IV of such Josephson Junctions in zero field and applied field. AC and DC Josephson Effect, Deriving the equations for the Josephson current in the presence of Magnetic flux (parallels with Diffraction phenomena), Quantum Interference Phenomena, Introduction and Discussion of the Superconducting Quantum Interference Device (SQUID). SQUID based Applications. RCSJ Model | 8 |
| Total number of lectures: | | | |

<u>Pre-requisites</u>: Phy412, Phy431, Phy432, Phy543
<u>Short summary for including in the Courses of Study Booklet</u>: Introduction to the Quantum mechanical phenomena of superconductivity and its fascinating manifestation as a macroscopic quantum phenomenon. We sample some of the rich diverse properties displayed by this phenomenon and the plethora of ancillary phenomena displayed by superconductors which have immense applications potential of which some have already been realized and used. We

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<tr><td></td><td></td><td></td><td>discuss some of these applications and devices based on superconductors which are increasingly finding use at the frontiers of Quantum technology.<br><br><u>Recommended books:</u><br>* Introduction to Superconductivity: A. C. Rose-Innes and E. H. Rhoderick<br>* Introduction to Superconductivity: Michael Tinkham Magnetic Flux structures in superconductors: R. P. Huebner<br>* Theory of superconductivity: J. R. Schrieffer<br>* Superconductivity Physics and Applications: Kristian Fossheim and Asle Sudbo<br>* Superfluidity and Superconductivity: D. R. Tilley and J. Tilley<br>* Experimental Techniques in Low Temperature Physics, Guy K White and Phillip J. Meeson.</td></tr>
<tr><td>PHY657</td><td>Advanced General Relativity</td><td>3-0-0-0 (9)</td><td><u>Objectives</u>: The objective of this course is to familiarise the student with advanced aspects of General Relativity relevant to current research in the topic. The concepts taught in the course will be useful not only for theoretical research in gravitational physics but also for those who wish to specialise in astrophysical phenomena in the strong gravity regime. The large amount of observational data expected in the near future should boost research on strong gravity and this course will provide the basic framework to address this exciting area.<br><br><u>Contents</u>:<br><table>
<tr><td>S. No.</td><td>Broad Title</td><td>Topics</td><td>No. of Lectures</td></tr>
<tr><td>1</td><td>Introduction and fundamentals</td><td>Tensors and their derivatives : covariant differentiation and Lie derivatives, Killing vectors. Geodesics and geodesic deviation. Locally flat metrics and Fermi normal coordinates.</td><td>8</td></tr>
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| | | | | | Elementary applications including radial and circular trajectories in a Schwarzschild background. | |
| | | | 2 | Geodesic congruence and the Raychaudhuri equation | Energy conditions and their relevance. Geodesic congruences for time like and null geodesics and Frobenius theorem. Derivation of the Raychaudhuri equation. Illustrations for simple cases including cosmological significance | 6 |
| | | | 3 | Gravitational Collapse | Hypersurfaces and the induced metric. Integration on hypersurfaces and the Gauss theorem. Intrinsic curvature and the Gauss Codazzi equations. Junction conditions and thin shells. Oppenheimer Snyder collapse and the formation of black holes. | 8 |

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| 4 | Lagrangian and Hamiltonian formulation | Lagrangian and Hamiltonian formulation Lagrangian and Hamiltonian formulations of General Relativity. 3 + 1 decomposition. ADM formalism. Definitions of mass and angular momentum. | 10 |
| 5 | Black Holes | Basic properties of Schwarzschild, Reissner-Nordstrom and Kerr black holes. Event horizon, apparent horizon and Killing horizon. Penrose diagrams. Introduction to the laws of black hole thermodynamics. | 8 |
| Total number of lectures | | | 40 |

Pre-requisites: PHY407.

Short summary for including in the Courses of Study Booklet: Tensors and their derivatives, geodesics and Fermi normal coordinates, energy conditions, Raychaudhuri equations, hypersurfaces and Gauss theorem, Gauss-Codazzi equations, junction conditions and thin shells, gravitational collapse, Lagrangian and Hamiltonian formulations of General Relativity, black holes, with charge and rotation, Penrose diagrams, black hole thermodynamics.

<table>
<tr><td></td><td></td><td></td><td>Recommended books:<br><br>I. A relativist's toolkit : the mathematics of black hole mechanics by Eric Poisson, Cambridge, 2007.<br>II. General Relativity by Robert Wald, University of Chicago Press, 1984.<br>III. Gravitation by C. W. Misner, K. S. Thorne, J. A. Wheeler; W. H. Freeman and co., 1973.<br>IV. Lecture notes by Mathias Blau (available online).</td></tr>
<tr><td>PHY658</td><td>Cosmology</td><td>3-0-0-0 (9)</td><td>Objectives: Explore the fascinating realm of modern cosmology, delving into the study of the Universe's contents and evolution. Covering topics such as expanding spacetime, the early Universe's thermal history, including nucleosynthesis and the cosmic microwave background, and the inflationary model for cosmic structure origins, this course offers students a comprehensive overview of contemporary cosmology. Beginning with the foundational principles of general relativity, we will develop models of an expanding universe and examine its correlation with the Universe's contents. From there, we will journey through the Universe's evolution, from its fiery beginnings to the synthesis of light elements and the emergence of the cosmic microwave background. Finally, we will explore the evolution of cosmological structures, from the generation of density fluctuations during inflation to the formation of bound halos.<br><br>Contents:
<table>
<tr><td>S. No.</td><td>Broad Title</td><td>Topics</td><td>No. of Lectures</td></tr>
<tr><td>1</td><td>Introduction</td><td>Observing the Universe, The expanding universe, timeline of key events, homogeneity & isotropy, units in cosmology</td><td>2</td></tr>
<tr><td>2</td><td>Hubble Law and Geometry of Space</td><td>Cosmological redshift, the Hubble law, symmetries of the space, Friedmann-</td><td>4</td></tr>
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| | | | | | Lemaitre-Robertson-Walker metric, geodesic equation, distances | |
| | | | 3 | Contents of the Universe | Perfect fluids, Continuity equation, Friedmann equations, single component universe, multi-component universe, exact solutions | 6 |
| | | | 4 | The Hot Big Bang | Early universe thermodynamics, thermal equilibrium, entropy in the universe, neutrinos in cosmology, decoupling of neutrinos, cosmic neutrino background, cosmic microwave background, Boltzmann equation, Big Bang nucleosynthesis, Baryogenesis | 10 |
| | | | 5 | Cosmological Inflation | Problems with the Hot Big Bang, Horizon Problem, Flatness problem, super horizon correlations, Inflationary solution, physics of inflation, scalar field dynamics, slow- | 8 |

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<tr><td></td><td></td><td>roll inflation, an invitation to reheating</td><td></td></tr>
<tr><td>6</td><td>Large Scale Structure of the Universe</td><td>Newtonian perturbation theory, growth of matter perturbations, Jeans instability, Linear growth function, Transfer function, Power spectrum, Harrison-Zel'dovich spectrum, structure formation, spherical collapse, Press-Schechter theory</td><td>10</td></tr>
<tr><td colspan="3">Total number of lectures:</td><td>40</td></tr>
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<u>Pre-requisites:</u> PHY 432/PHY 626, PHY 412.<br>
Short summary for including in the Courses of Study<br>
<br>
<u>Booklet:</u> The Expanding Universe, Dynamics of Spacetime, Cosmological Solutions; The Hot Big Bang, Recombination, Big Bang Nucleosynthesis, Cosmic Neutrino background, Cosmic Microwave Background; Cosmological inflation, Structure Formation, Density Perturbations, Power Spectrum, Large Scale structure of the Universe.<br>
<br>
<u>Recommended books:</u><br>
l. Cosmology, D. Baumann, Cambridge University Press.<br>
ll. Modern Cosmology, S. Dodelson & F. Schmidt, 2nd ed., Academic Press.<br>
Ill. The Early Universe, E. W. Kolb and M. S. Turner, Westview Press.<br>
IV. Cosmology, S. Weinberg, Cambridge University Press.
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<td>PHY664</td>
<td>Photonic Devices</td>
<td>3-0-0-0 (9)</td>
<td><u>Overview:</u> The course aims at providing the knowledge base of modern photonic devices</td>
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| | | | through an indepth analysis of the underlying physical concepts and the necessary discussions on technological challenges. The course is targeted at students who are inclined towards practical aspects of photonics along with the basics.<br><br><u>Course highlights:</u><br>* Strong emphasis on the theoretical concepts of Photonics<br>* Introduction to modern photonic technologies<br>* Sufficient importance to active and passive photonic devices<br>* Discussion on practical aspects and challenges in characterizing photonic devices<br><br><u>Contents</u>: |

| S. No. | Broad theme | Contents | Lectures (of 50 min. duration) |
|---|---|---|---|
| 1 | Light-matter interaction — a review | Dispersion in dielectrics, consequence of interference and diffraction | 5 |
| 2 | Periodic structures as optical devices | Optical multi-layers, diffraction gratings, photonic crystals | 5 |
| 3 | Fiber optic devices | Modal theory, devices for wavelength-, direction- and polarization-selectivity, Bragg gratings | 6 |
| 4 | Integrated-optic devices | Coupled-mode theory, waveguides and couplers in silicon platform | 6 |
| 5 | Light source | Significance of using LED and laser sources | 4 |

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| 6 | Electro-optic and optoelectronic devices | Modulators, photodetectors and solar cells | 4 |
| 7 | Novel devices | Plasmonic sensors, slow light devices | 5 |
| 8 | Device characterization | Measurement techniques in time- and spectral-domain | 5 |
| Total number of lectures: | | | 40 |

Pre-requisites: Basic electromagnetic theory and basic optics/photonics.

Short summary for including in the Courses of Study Booklet: Light-matter interaction — a review, periodic structures such as Bragg reflectors, gratings and photonic crystals, fiber-optic devices, integrated-optic devices, active devices, sensors, measurement and characterization techniques.

Target group: Masters and doctoral students of PHY, CELP and EE.

Recommended books:

- Thomas P.Pearsall, Photonics essentials, 2nd Ed., Mc-Graw Hill (2010)
- Jia-Ming Liu, Photonic Devices, Cambridge University Press (2005)
- Grote and Venghaus, Fiber optic communication devices, Springer (2001)
- Zeev Zalevsky and Ibrahim Abdulhalim, Integrated nanophotonic devices, 2nd Ed., Elsevier (2014)
- Larry A. Coldren, Scott W. Corzine and Milan L. Masanovic, Diode lasers and photonic integrated circuits, 2nd Ed., John-Wiley and Sons (2012)
- Mark A. Mentzer, Applied optics fundamentals and device applications, CRC Press (2011) Vil. A. Dmitriev (Ed.), Nanoplasmonic sensors, Springer (2012)
- Jacob Khurgin and Rodney Tucker, Slow light, CRC Press (2008).

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<td>PHY684</td>
<td>Introduction to Plasma Astrophysics</td>
<td>3-0-0-0 (9)</td>
<td>
<u>Objectives</u>: Astrophysical phenomena, from the majestic glowing of stars to the enigmatic dynamics of galaxies, are intricately woven from the fabric of natural plasmas. Delving into these wonders requires a profound grasp of plasma physics—an indispensable tool for unravelling the mysteries of the universe. This course offers an enthralling journey through the intricate tapestry of astrophysical plasma physics.<br>
Starting with the definition, basic properties and systematic classification of plasmas, an encouraging discussion wilt be dedicated to various plasma sources and important examples of astrophysical plasmas. Along with a meticulous exploration of single particle motion within plasmas, this course will voyage through the kinetic theory and the fluid models of plasma. tn the framework of single fluid model magnetohydrodynamics (MHD), several aspects of solar plasma i.e. the sunspot, solar flare, CMEs, solar wind turbulence will be discussed.<br>
Besides theory, this course also provides an opportunity for hands-on exploration of astrophysical data analysis. Starting from deciphering numerical simulations to unravelling the mysteries hidden within in-situ spacecraft data, students will gain invaluable insight into the tools of modern astrophysics thus aiming at a brilliant career in the understanding of the cosmos.<br><br>
<u>Contents</u>:
<table>
<tr><th>S. No.</th><th>Broad Title</th><th>Topics</th><th>No. of Lectures</th></tr>
<tr><td>1.</td><td>Introduction</td><td>Basic properties, characteristic length scales and times scales of plasmas, classification of plasmas, plasma sources, examples of space and astrophysical plasmas</td><td>5</td></tr>
<tr><td>2.</td><td>Single particle dynamics</td><td>Motion of single charged particle in electromagnetic</td><td>6</td></tr>
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| | | fields, ExB drift, gradient drift and curvature drifts, adiabatic invariants, vanAllen belt, auroras | |
| 3. | Kinetic and fluid descriptions of plasma | Kinetic model of a plasma, introduction to Vlasov's equation and derivation of multi-fluid models; derivation of equations in ordinary magnetohydrodynamics (MHD), extension to Hall and electron MHD models | 9 |
| 4. | MHD plasma | Properties of MHD fluids, magnetic tension and pressure, ideal conservation, linear wave modes, instability, incompressible MHD and Elsasser variables, reconnection, MHD turbulence, MHD dynamos | 12 |
| 5. | Solar plasma as an MHD fluid | Study of solar plasma; sunspot, solar flare, CME, solar wind turbulence, solar dynamo etc. | 8 |
| | | Total number of lectures: | 40 |

Pre-requisites: None

Short summary for including in the Courses of Study Booklet: definition and classification of plasmas, motion of a single charged particle in a plasma, kinetic theory of plasma, derivation of the

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| | | | multi-fluid equations, reduction to the simplest single fluid magnetohydrodynamics (MHD) model, properties of an MHD plasma, ideal invariants of MHD, linear modes and linear instabilities of MHD, case study with solar plasma as an MHD fluid: sunspot, solar flare, CME, solar wind turbulence, solar dynamo etc., hands-on exploration of astrophysical data analysis<br><br><u>Recommended books:</u><br>• Basic Space Plasma Physics, Wolfgang Baumjohann and Rudolf A. Treumann (World Scientific Publishing, 1996)<br>• The Physics of Fluids and Plasmas, Arnab Rai Chaudhuri (Cambridge University Press, 1998)<br>• Plasma physics for astrophysicists, Russell M. Kulsrud (Princeton University Press, 2004)<br>• Compressible turbulence in space and astrophysical plasmas : Analytical approach and in-situ data analysis for the solar wind, Supratik Banerjee (Ph. D. Thesis, 2014) |