M.Sc Electives 3 0 0 6

Electives have to be taken from at least two different groups. One of the electives can be taken from Institute electives available.

Group-I: Condensed Matter

PH521: Topics in Condensed Matter Physics

Second Quantization, Diagrammatic Perturbation Theory, Bose and Fermi Liquid Examples; Electron Gas, Hartree Fock Approximation, Dielectric Response, Hubbard Model; Electron-Phonon Interaction, Superconductivity, BCS Theory; Low Dimensional Magnetic Systems, Spin Representations, Linear and Nonlinear Spin Wave Theory, Heisenberg Antiferromagnet, XY Model.

References:

1. W. Fetter and J. D. Walecka, *Quantum Theory of Many-Particle Systems,* McGraw Hill (1971).
2. G. D. Mahan, *Many-Particle Physics,* Plenum Press (1990).
3. C. Kittel, *Quantum Theory of Solids,* John Wiley (1987).
4. M. Tsvelik, *Quantum Field Theory in Condensed Matter Physics,* CUP (1995).
5. N. Nagaosa, *Quantum Field Theory in Condensed Matter Physics,* Springer-Verlag (1999).
6. J. W. Negele and H. Orland, *Quantum Many-Particle Systems,* Addison-Wesley (1988).
7. A. Auerbach, *Interacting Electrons and Quantum Magnetism,* Springer Verlag (1998).
8. E. Fradkin, *Field Theories of Condensed Matter Systems,* Addison Wesley (1991).
9. P. W. Anderson, *Basic Notions of Condensed Matter Physics,* Addison Wesley (1997).

PH522: Physics of Semiconductors

Energy Band Structure, occupation probabilities, Impurities and Imperfection in Semiconductors, carrier concentration in thermal equilibrium, Electron Transport Phenomenon, Thermal Effects in Semiconductors, Excess Carriers in semiconductors, recombination, contact phenomenon, Photoconductivity, Photovoltaic Effect, Scattering Process in Semiconductors: Optical and high frequency effects in semiconductors, Semiconducting Materials, Amorphous semiconductors, structural and electronic properties, applications of amorphous semiconductors.

References:

1. R. A. Smith, *Semiconductors,* Academic Press (1978).
2. K. Seeger, *Semiconductor Physics: An introduction,* Springer Verlag (1991).
3. C. Hamaguchi, *Basic semiconductor physics,* Springer verlag (2001).
4. J. Singh, *Physics of semiconductors,* Tata Mcgraw Hill (1993).
5. K. Morigaki, *Physics of Amorphhous Semiconductor,* Imperial college Press (1999).

PH523: Magnetism and Superconductivity

Magnetism: Review of diamagnetism, paramagentism, ferromagnetism, antiferromagnetism, ferri magnetism. Circular and helical order. Direct, exhange, double exchange, indirect and RKKY interactions. enviroment effects: crystal field, tetrahedral and octahedral sites; Jahn- Teller effect; Hund's rule and rare earth ions in solids. Consequences of broken symmetry, phase transition, Landau's theory, rigidity, excitation, magnons, domains and domain walls, magnetic hysteresis, pinning effects. Magneto resistance, giant magneto resistance, nuclear magnetic resonance, technological aspects of magnetic materials. Superconductivity: Properties of conventional (low temperature) superconductors, London and Pippard equation, Type II superconductors, intermediate state, vortex lines; flux pinning; Non-ideal behaviour of Type II superconductors; Thermodynamics of Type I and II superconductors; Ginzburg Landau (G-L) theory; G-L equations; current density; Josephson equations; superconducting quantum interference device. Cooper pairs and BCS theory; Energy gap; magic number; experimental determination of energy gap from 1- V characteristics; McMillan's upper limit of Tc. Properties of high Tc superconductors, flux pinning, current density, granular nature. Technological aspects of superconductors.

References:

1. S. Blundell, *Magnetism in Condensed Matter,* Oxford (2001).
2. D. Craik, *Magnetism: Principles and Applications,* John Wiley (1995).
3. J. B. Ketterson and S. N. Song, *Superconductivity,* Cambridge (1999).
4. T. P. Sheahen, *Introduction to high-temperature Superconductivity,* Plenum (1994).
5. M. Tinkham, *Introduction to Superconductivity,* McGraw Hill (1996).
6. A. C. Rose-Innes and E. H. Rhoderick, *Introduction to Superconductivity,* Pergamon (1978).

PH524: Thin Film Phenomena

Theory: Basic definitions; thin film deposition methods: PVD, CVD, Epitaxy, theory of nucleation & growth in thin films, defects, diffusion, methods of control and measurement of film thickness, Structural, optical, electrical and mechanical characterization of films, metallic, semiconducting and insulation films, non-crystalline films, applications of thin films. Laboratory work: Vacuum evaporation of thin films, Physical characterization of evaporated films.

References:

1. 1.M. Ohring, *The Material Science of Thin Films,* Academic (1992). 2. A.
2. Goswami, *Thin Film Fundamentals,* New Age (1996).
3. A. Wagendristel and Y.Wang, *An introduction to Physics and Technology of Thin Films,* World
4. Scientific (1994)
5. J. George, *Preparation of Thin Films,* Marcel Dekker Inc (1992).

PH525: Optoelectronic Materials and Devices

Materials for optoelectronics: Structural properties of crystalline, polycrystalline, amorphous materials, liquid crystals, interfaces, and defects in materials; Electronic properties of semiconductors: band structures, doping and carrier transport; Optical properties of semiconductors: interband and intraband transitions, charge injection and radiative/nonradiative recombination, exitonic effects; Light detection and imaging: Solar cell, Photoconductive detectors, Phototransistor, Metalsemiconductor detector, Charge coupled devices; Light emitting diode: Operation and advanced structures, Laser diode: Spontaneous and stimulated emission, laser structures, time response of lasers, advanced semiconductor laser structures, temperature dependence of laser output. Liquid crystal display, Electro-optic modulators, Interferrometric modulators, directional couplers, properties of optical fibers; Fabrication and processing of devices: Bulk crystal growth and epitaxial crystal growth, lithography, etching, fabrication of optical fibres, fibre coupling and splicing

Texts:

1. Jasprit Singh, *Optoelectronics: An introduction to Materials and Devices*, McGrawHill Inc, 1996.

References:

1. S.O.Kasap, *Optoelectronics and photonics: principles and practices*, Prentice Hall 2001.
2. 2.Jasprit Singh, *Semiconductor Optoelectronics: Physics and Technology*, McGraw Hill Inc. 1995.
3. Pallab Bhattacharya, *Semiconductor Optoelectronic Devices*, Prentice-Hall. 1995.

PH526: Soft Condensed Matter

Forces, Energies, and time scales: Intermolecular forces in Gases, liquids, and solids. Viscous, elastic and viscoelastic behaviour. Liquids and Glasses. Phase transitions: Review of critical phenomena through percolation. Phase transition in soft matter. Equilibrium phase diagrams, Kinetics of phase separation, Growth processes, Liquid-Solid transition, freezing and melting. Polymers: Synthesis, Polymer Chain Conformation, Flory theory, Characterization, Polymer solutions, Bioploymers. Colloids: Types of Colloids, Characterization of Colloids, Charge and steric Stabilization, Kinetic properties, Forms of colloids: Sols, Gels, Clays, Foams, Emulsions, Electrorheological and Magnetorheological fluids. Amphiphilies: Types of Amphiphilies, Surface activity, Surfactant Monolayers and LangmuirBlodgett Films, detergency, solubilzation in Micelles, Interfacial curvature and Molecular structure, liquid Crystal phase, membranes, templated structure. Liquid Crystals: Types of liquid crystals, Characterization and identification of liquid crystal phases, Orientational order, elastic properties, Phase transition in liquid crystals, Applications. Granular Materials through sandpile model and self-organized criticality.

References:

1. Ian W. Hamley, *Introduction to Soft Matter,* John Wiley (2000).
2. R. A. L. Jones, *Soft Condensed Matter,* Oxford (2002).
3. D. Stauffer and A. Aharony, *Introduction to Percolation Theory,* Taylor and Frnacis (1994).
4. M. V. Gandhi and B. S. Thompson, *Smart Materials and Structures,* Chapman and Hall (1992).
5. H. J. Jensen, *Self-Organized Criticality,* Cambridge (1998).

PH 527: Nanostructured Materials 3-0-0-6

 Wave function, Quantum confinement, 2 dimensional, 1 dimensional and 0 dimensional systems, Energy quantization and quantum phenomena. Phenomena at nanoscale: Nanoscale electrical transport, nano-magnetics, nanoscale thermal transport. Nanomaterial systems: Metallic, semiconducting, Quantum dot and quantum superlattice, polymer, nanocomposites, carbon based nanostructures, nanowires, photonic crystals, self-asembled nanostructures, Synthesis of nanomaterials, clusters, particles, fullerences, nanostructures Characterization of nanomaterials: X-ray diffraction, transmission electron microscopy, Scanning electron microscopy, Scanning near-field optical microscopy, other Scanning probes for imaging and manipulation, optical and vibrational spectroscopy, electrical, magnetic and electrochemical methods. Applications of nanomaterials in electronics, photonics, biotechnology, nano-electromechanical systems (NEMS).

References:

1. Nanomaterials: Synthesis, properties and Applications, Ed. A. S. Edelstein and R.C.Cammarata, IOP (UK, 1996). Characterization of nanophase materials: Ed. Z.L.Wang, Willey-VCH (New York, 2002).
2. Introduction to nanotechnology, Charles P. Poole and Frank J. Owens (Wiley-Interscience, May 2003).
3. Naostructured Materials, Ed. Jackie Yi-Ru Ying (Academic Press, Dec 2001).
4. Nanotechnology: Basic Science and emerging technologies, Ed. Michael Wilson, K.Kannangara, G. Smith, M. Simmons, and C. Crane (CRC Press, June 2002).

PH528: Spintronics: Physics and Technology 3-0-0-6

(Pre-requisite: PH505 or equivalent)

History and overview of spin electronics, quantum mechanics of spin, spin-orbit interaction, exchange interaction, spin relaxation mechanisms, spin-dependent electron transport, spin-dependent tunneling, basic theory of Andreev reflection, ferromagnet/ superconductor/ ferromagnet double junctions, spin-transfer torque and its magnetic dynamics, current-driven switching of domain wall motion, domain wall scattering and current-induced switching in ferromagnetic wires, spin injection, spin accumulation, spin current, spin Hall effect, spin photoelectronic devices, electron spin filtering, materials for spin electronics, nanostructures for spin electronics, fabrication techniques, spin-valve and spin-tunneling devices, spintronic biosensors, quantum computing with spins.

Texts and References:

1. S. Bandyopadhyay, M. Cahay, *Introduction to spintronics*, CRC Press, 2008.
2. M. Johnson, *Magnetoelectronics*, Academic Press 2004.
3. S. Maekawa, *Concepts in spin electronics*, Oxford University Press, 2006.
4. D.D. Awschalom, R.A. Buhrman, J.M. Daughton, S.V. Molnar, and M.L. Roukes, *Spin electronics*, Kluwer Academic Publishers, 2004.
5. Y.B. Xu and S.M.Thompson, *Spintronic materials and technology*, Taylor & Francis, 2006.

PH 530: Organic Electronics and Optoelectronics 3-0-0-6

Molecules to Aggregates-Organic molecules; covalent bond-sigma and pi bonds, electronic structures of atoms and molecules; energy levels; organic films; organic solids; excited states of aggregated films; excitons and exciton diffusion; Conducting polymers-oligomers, semiconducting small organic molecules and their properties; Charge transport and optical processes in organic films. Organic light emitting diodes (OLED); fabrication techniques, performance, way to perceive colors, conventional, transparent, inverted and flexible OLEDs, OLED based flexible display technology; Organic thin films transistors (OTFT) - Fabrication techniques, performance, applications, single molecule switch and memory element, organic nanotube transistors, OTFT based display technology; Organic laser-Lasing process, optically pumped lasing structures, applications; Organic multilayer photodetectors; organic photovoltaic cells; Organic spintronics-spin transport through organic films, spin valves, applications.

Texts and references:

1. F. So, *Organic Electronics: Materials, Processing, Devices and Applications,* CRC Press, 2010.
2. H. Klauk, *Organic Electronics: Materials, Manufacturing and Applications,* Wiley-VCH, 2006.
3. G. Meller and T. Grasser, *Organic Electronics,* Springer, 2010.
4. W. Brutting, *Physics of Organic Semiconductors,* Wiley-VCH, 2005.
5. J. Kalinowski, *Organic Light-Emitting Diodes: Principles, Characteristics, and Processes,* Marcel Dekker, 2005.
6. Z. Bao and J. Locklin, *Organic Field Effect Transistors,* CRC Press, 2007.
7. F. C. Krebs, *Polymer Photovoltaics: A Practical Approach,* SPIE Press, 2008.
8. Z. V. Vardeny, *Organic Spintronics,* CRC Press, 2010.

PH542: Phase Transitions and Critical Phenomena

Critical Phenomena: Phase transitions in different systems, First order and second order, Thermodynamics and statistical mechanics of phase transition, Critical point exponents and exponent inequalities. Models: Spin-l/2 and Spin-l Ising Models, q-state Potts model, X-Y and Heisenberg models. Universality. Mean Field Theory: Mean Field Theory for Ising model, Landau theory, Correlation functions, Classical mean field theories, Scaling hypothesis. Transfer matrix: Setting up the transfer matrix, Calculation of free energy and correlation functions, Results of Ising model. Series Expansion: High and low temperature series, application in 1-d Ising model, Analysis of series. Monte Carlo: Importance sampling, Metropolis algorithm, Data analysis, statistical error, finite-size effect. Examples Renormalization Group: Definition of a RG transformation, Flow in parameter space, Universality, Scaling and critical exponents, scaled variables. Application in 1-d Ising model.

References:

1. H. E. Stanley, *Introduction to Phase transitions and Critical Phenomena,* Oxford (1971).
2. J. M. Yeomans, *Statistical Mechanics of Phase transitions,* Oxford (1992).
3. K. Huang, *Statistical Mechanics,* John Wiley (2000).
4. R. K. Pathria, *Statistical Mechanics,* Oxford (1999).
5. M. Plischke and B. Bergersen, *Equilibrium Statistical Physics,* Prentice Hall (1989).

PH552: Topological Phases of Matter (3-0-0-6)

Symmetries of the Hamiltonian, Inversion and time reversal symmetries, Kramer's theorem, Kramer's degeneracy, simple one dimensional systems, Su-Shrieffer-Heeger model of polyacetylene, bulk-edge correspondence, edge states, chiral symmetry, topological invariant, Kitaev model, Majorana modes, 4π Josephson effect, Andreev conductance quantization.
Quantum Hall effect, TKNN invariant, Anomalous quantum Hall effect, Haldane model, Chern insulator, accidental degeneracy, Berry curvature, Berry phase, Chern number.
Two dimensional topological insulators, spin-orbit couplings, Graphene, Chiral edge modes in Graphene, Kane Mele model, band inversion, strained semiconductors, topological phase in HgTe-CdTe quantum wells, spin Hall effect, Quantum spin Hall insulators, conductance characteristics, spin polarized conductance, helical edge modes, applications to spintronics.
Semi-Metals: Topological aspects of semi-metals, Weyl equation, Weyl semi-metal, Weyl nodes, Fermi arcs, violation of inversion and time reversal symmetries, surface states, simple two band models, type-I and type-II semi-metals, Dirac semi-metals, experimental scenario, Quantum oscillations.

Texts/References

1. F. Ortmann, Topological Insulators: Fundamentals and Perspectives, Wiley-VCH (2015), 1st Ed.

2. Ed. by G. Tkachov, Topological Insulators: The Physics of Spin Helicity in Quantum Transport, CRC press (2016), 1st Ed.
3. János K. Asbóth, László Oroszlány, András Pályi, A Short Course on Topological Insulators: Band Structure and Edge States in one and two dimensions, Springer (2016), 1st Ed.
4. B. Andrei Bernevig, Topological Insulators and Topological Superconductors, Princeton University Press (2013) 1st Ed.
5. A.M. Turner, V. Ashwin, Beyond band insulators: Topology of semi-metals and interacting phases, (arXiv 1301.0330(V2))

Group-II: Lasers and Photonics
PH 531: Laser Physics

Interaction of radiation with matter, semi classical theory, stimulated emission, life times and line widths, Laser rate equations, gain coefficient, threshold conditions, gain saturation, optimum output coupling, cw and pulsed operation, pumping mechanism theory of optical resonator, longitudinal and transverse modes, Q switching, mode locking, pulse compression, different types of lasers, laser amplifier, applications of laser

References:

1. O. Svelto, *Principles of Laser,* Plenum (1998).
2. W. T. Silfvast, *Laser and Fundamentals,* Cambridge (1996).
3. A. E. Seigman, *Lasers,* Oxford (1986).
4. A. Yariv, *Quantum Electronics,* John Wiley (1988).

PH 532: Laser Spectroscopy

Interaction of radiation with matter, strong field approximation, Rabi oscillations, line widths, Doppler limited spectroscopy, laser induced absorption and fluorescence spectroscopy, optogalvanic spectroscopy, high resolution spectroscopy, double resonance techniques, Laser Raman spectroscopy, time resolved laser spectroscopy, homodyne and hetrodyne spectroscopy, measurement of ultra short pulses, pump and probe techniques, quantum beat spectroscopy, photon echo, correlation spectroscopy, single ion spectroscopy, atom interferometry, polarization spectroscopy, Laser cooling, multiphoton transitions.

References:

1. W. Demtroder, *Laser Spectroscopy Basic Concepts and Instruments,* Springer (1996).
2. M. S. Feld and V. S. Lethokov, *Non linear laser Spectroscopy,* Springer (1980).
3. S. Stenholm, *Foundations of laser spectroscopy,* Wiley (1999).
1. 4.V. I. Balykin and V. S. Lethokov, *Atom Optics with Laser Light,* Harwood Academic Publishers (1995).

PH 533: Non Linear Optics

Introduction to Nonlinear Optics: Optics & Wave propagation in anisotropic medium, Electromagnetic Waves in Nonlinear Media, Phenomenological theory of nonlinearities, Nonlinear polarization. Second Order Nonlinear Optics: Electro-Optic and Acousto-optic effects, Acousto-optic Modulators, Harmonic generation, Phase Matching, Parametric Effects, Photorefractive Effect. Third-order Nonlinear Optics: Wave Mixing; Nonlinear Refraction and Absorption, Multiphoton Processes, Self-focusing, Self-phase-modulation, Photon Echo, Optical Switching and Solitons. Stimulated Scattering: Rayleigh, Brillouin, and Raman Processes. Nonlinear optical Techniques & Materials: Z-Scan, Four-Wave Mixing, Third Harmonic Generation, Non-Linear Optics of Organics, Semiconductors, Glasses, Polymers, Fiber and Nanostructures.

Texts:

1. Robert W. Boyd, *Nonlinear Optics,* Academic Press, New York, 1992.
2. Y. R. Shen, *The Principles of Nonlinear Optics,* New York, J. Wiley, 1984.

References:

1. G S He & S H Liu, *Physics of Nonlinear Optics*, World Scientific, Singapore, 2000.
2. P.N. Butcher and D. Cotter, *The Elements of Nonlinear Optics*, Cambridge University Press, New York, 1990
3. A. Yariv, *Optical Electronics in Modern Communications,* Oxford University Press, 1997.
4. A. K. Ghatak & K. Thyagarajan, *Optical Electronics*, Cambridge University Press,(1991).
5. R.L. Sutherland, *Handbook of Nonlinear Optics*, Marcel Dekker Inc., 2003.

PH 534: Fibre Optics

Fiber numerical aperture, Ray and modal analysis of Step/graded index multimode fibers, Single mode fiber, Mode cutoff and mode field diameter. Loss mechanism in optical fiber, Pulse dispersion and chirping in single-mode fibers, Dispersion compensation mechanism, Dispersion-tailored and dispersion compensating fibers, Birefringent fibers and polarization mode dispersion, Fiber bandwidth. Nonlinear effects: Stimulated Raman Scattering, Stimulated Brillouin Scattering, Self Phase Modulation, Cross Phase Modulation, Optical Solitons. Fiber based devices: Sensors, Erbium-doped fiber amplifiers and lasers, Fiber Bragg gratings. Photonic Crystal and Holey fibers. Experimental technique: Fiber fabrication and characterization, Splices, Connectors and fiber cable.

Texts:

1. A. K. Ghatak & K. Thyagarajan, *Introduction to Fiber Optics*, Cambridge University Press (1998).

2. G. P. Agarwal, *Fiber Optic Communication Systems*, John Wiley Sons (1997).

References

1. J. M. Senior, *Optical Fiber Communication,* Prentice Hall (1999).
2. G. Keiser, *Optical Fiber Communications,* McGraw Hill (2000).
3. P. N. Prasad, *Nanophotonics,* Wiley-Interscience (2004)
4. K. Okamoto, *Fundamentals of Optical Waveguides,* Academic Press, (2000).
5. K. Iizuka, *Elements of Photonics Vol I &II,* Wiley-Interscience (2002).

PH 535: Integrated Optics Devices

Ray and modal analysis of planner step-index/graded index waveguides, Guided and radiation modes, Ray and modal analysis of asymmetric waveguides, Strip and channel waveguides, segmented waveguides. Integrated optic devices: Directional couplers & optical switches Coupled mode theory, Co-directional & contra-directional coupling, Phase & amplitude modulators, Filters, Y-junction, Power splitters, Arrayed waveguide devices, Waveguide amplifiers, Distributed Feed-back lasers. Fabrication of integrated optical waveguides and devices: Ion-exchange, Epitaxial Growth, Ion implantation; Waveguide loss measurement: Scattering and Absorption loss; End-fire and prism coupling, Fiber pig-tailing, End-butt coupling

Texts

1. A. K. Ghatak & K. Thyagarajan, *Optical Electronics*, Cambridge University Press, (1991).
2. D. Marcuse, *Theory of Dielectric Optical Waveguide*, Academic Press, New York (1974).

References

1. T. Tamir, *Integrated Optics*, Springer-Verlag Berlin Heidelberg New York (1975).
2. A. W. Snyder & J D Love, *Optical Waveguide Theory*, Chapman and Hall, London (1983).
3. R. G. Hunsperger, *Integrated Optics: Theory & Technology*, Springer (2002).
4. K. Okamoto, *Fundamentals of Optical Waveguides*, Academic Press, (2000).

PH536: Quantum Optics

Pictures of Quantum mechanics. Density matrix formalism. Two-level model of atom, Interaction with an electromagnetic field, Bloch equation, Density matrix treatment. Quantization of electromagnetic field, Commutation relations, Momentum and spin of a photon, Fock states, Lamb Shift, Quantum beats. Models: Dicke Hamiltonian, Jaynes-Cummings model. Stochasticity: Langevin equation, Fokker-Planck equation, Master equation for a harmonic oscillator and a two-level atom, Characteristic function, Quasi-probability distribution. Coherence: Correlation functions, Hanbury-Brown Twiss effect, Quantum correlation functions, Bunching and anti-bunching effects. Coherent and Squeezed states: Squeezed coherent states, Fock state representation, Coherent state representation, Q-representation, Wigner-Weyl distribution, Squeezed states of a two-mode electromagnetic field, Squeezing in the Jaynes-Cummings model. Resonance fluorescence, Dressed canonical transformation, Transition among dressed states, Line width, Intensity distribution, Density matrix theory. Optical Bistability: Construction of quantum mechanical Hamiltonian, Master equation. Virtual photon effects: Time evolution of phase operator, Phase fluctuation, Effect of virtual photons on squeezed states.

References:

1. C. Cohen-Tannoudji, J. Dupont-Roc, and G. Grynberg, *Atom-Photon Interaction: Basic Processes and Applications*, John Wiley, 1992.
2. S. M. Barnett and P. M. Padmore, *Methods of Theoretical Quantum Optics*, Clarendon Press, Oxford, 2002.
3. D. F. Walls and G. J. Milburn, *Quantum Optics*, Springer Verlag, 1995.
4. M. O. Scully and M. S. Zubairy, *Quantum Optics*, Cambridge University Press, 1997.
5. J. S. Peng and G. X. Li, *Introduction to Modern Quantum Optics*, World Scientific, 1998.
6. C. Cohen-Tannoudji, J. Dupont-Roc, and G. Grynberg, *Photons and Atoms: Introduction to Quantum Electrodynamics*, John Wiley, 1989.
7. L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge University Press, 1995.
8. R. Loudon, *The Quantum Theory of Light*, Clarendon Press, Oxford, 1997.

PH537: Imaging and Fourier Optics 3 0 0 6

Paraxial geometrical optics: Matrix formulation of lens and mirrors, images by thin lenses, stops and pupils.
Wavefront aberrations: Aberration polynomial, primary aberrations, Seidel aberrations, Zernike polynomials, chromatic aberration, wavefront shaping.
Scalar diffraction theory: Kirchhoff formulation, Fresnel and Fraunhofer diffraction, applications of Fraunhofer diffraction formula: rectangular and circular aperture, periodic objects.
Fourier optics: Fourier transforming properties of a lens, diffraction limited imaging systems, point spread functions, Airy pattern, convolution, point spread function with aberrations, Strehl ratio, coherent and incoherent imaging, optical transfer function, and resolution limit.
Applications: High resolution imaging using beam scanning microscopes, holography, optical pattern recognition, encryption, optical security system.

Text and References:

1. J W Goodman, *Introduction to Fourier Optics*, McGraw-Hill (2004)
2. E Hecht, *Optics*, Pearson Education (2008)

3. M Born and E Wolf, *Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light*, Cambridge University Press (1999)
4. E G Steward, *Fourier Optics: An introduction*, Dover Publication (2004)

Group-III: Theoretical Physics
PH541: Quantum Computation and Quantum Information

Superposition principle, the idea of a qubit, basis states, Hilbert space, projection operator, measurement; Bipartite Systems: tensor product, product and coupled bases, entanglement; Einstein-Podolsky-Rosen arguments and incompleteness, hidden variables, Bell inequalities, CHSH inequality, Aspect's experiment; Tripartite systems: GHZ states and entanglement. Quantum logic gates: Hadamard, controlled-NOT, and Toffoli gates, quantum circuits, nocloning theorem, quantum teleportation, dense coding Protocol; Quantum Algorithms: computational complexity, quantum parallel computation, Deutsch, Deutsch-Jozsa, and Simon's algorithm, Grover's search algorithm, Quantum Fourier transform, Shor's algorithm, phase estimation algorithm. Entropy and Information: Shannon's measure of information, mutual information and capacity of a channel, efficiency and redundancy, encoding, noiseless coding theorem, memory less channels, error correcting codes, Density matrix formulation, von Neumann entropy, POVM, entanglement quantification, decoherence. Quantum error correction: Shor's and Steane's codes, fault tolerant quantum computation; Quantum cryptography: quantum key distribution, BB84, B92, and EPR protocols, quantum privacy and security; Physical realizations of quantum computers: Linear ion-trap, NMR, and quantum dot devices.

Text Book:

1. M. A. Nielsen and I. A. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, New Delhi, 2002.

References:

1. R. P. Feynman, R. B. Leighton, and M. Sands, *The Feynman Lectures on Physics*, vol.3, Addison Wesley/Narosa, New Delhi, 1998.
2. R. P. Feynman, R. W. Allen, and T. Hey, *The Feynman Lectures on Computation*, Westview Press/Perseus Book Group, 1999.
3. J. J. Sakurai, *Modern Quantum Mechanics*, Addison-Wesley/Pearson Education, 1994.
4. D. Bouwmeester, A. Ekert, A. Zeilinger (Eds.), *The Physics of Quantum Information*, Springer, 2000.

PH543: Quantum Field Theory

Action principle, Cannonical Transformations, Poisson Brackets, Symmetries and conservation laws, Green's functions, Klein Gordon equation, Dirac equation, Free propogators Quantization of fields, Real and charged scalars, Massless and massive vector and spinor fields Perturbation

Theory, Feynman Rules, Regularization schemes, Renormalizability, Renormalization group equations, QED and Electroweak Interactions.

References:

1. C. Itzykson and J. B. Zuber, *Quantum Field Theory,* McGraw Hill (1985).
2. P. Ramond, *Field Theory: A Modern Primer,* Addison-Wesley (1990).
3. T. P. Cheng and L. F. Li, *Gauge Theory of Elementary Particle Physics,* Clarendon Press, Oxford, 1984.
4. 3.K. Huang, *Quantum Field Theory From Operators to Path Integrals,* John Wiley (1998).

PH 544: High Energy Physics

Introduction: Colliders, Detectors, Klein-Gordon Equation, Dirac Equation, Antiparticles; Gauge Field Theory: Particle Interactions, S-Martrix, Cross Sections; Quantum Electrodynamics (QED): Feynman Rules, Elementary processes, Higher-order Corrections, Lamb Shift, Renormalization; Quantum Chromodynamics (QCD): Structure of Hadrons, Parton Model, Bjorken Scaling, Quarks, QCD, Aymptotic Freedom, Confinement, Chiral Symmetry, Feynman Rules, Elementary Processes, Renormalization; Weak Interactions: $V-A$ Theory, Weak Mixing Angles, CP violation; The Standard Model: Electroweak Interactions, $SU(2)\times U(1)$ Gauge Symmetry, Spontaneous Symmetry Breaking, Higgs Mechanism, Renormalizability, Collider Experiments, Neutrinos; Beyond the Standard Model: Supersymmetry, Grand Unified Theories, Ideas in String Theory.

Text:

1. Francis Halzen and Alan D. Martin: *Quarks and Leptons: An Introductory course in Modern Particle Physics;* John Wiley & Sons (1984)

Reference:

1. M.E. Peskin and D.V. Schroeder: *An Introduction to Quantum Field Theory*; Westview Press (1995)
2. D.H. Perkins: *Introduction to high energy physics-4th Edn.*; Cambridge University Press (2000).
3. C. Itzykson and J.B. Zuber: *Quantum Field Theory*; McGraw Hill (1986).
4. Ta-Pei Cheng and Ling-Fong Li: *Gauge Theory of Elementary Particle Physics*; Oxford University Press (1992)
5. T. Muta: *Foundations of Quantum Chromodynamics*; World Scientific (1987)

PH545: General Theory of Relativity

Review of Riemannian geometry: Metric tensor, covariant differentiation, curvature tensor, Bianchi Identities, Ricci tensor. Motion of a particle in a gravitational field, geodesic. Equations of electrodynamics in the presence of a gravitational field. Gravitational field equations: Action for gravitational field, Energy-momentum tensor, Extremum principle, Einstein field equations, Energy-momentum pseudotensor. Field of gravitating bodies: Schwarzschild solution, Birkhoff's theorem, Motion in a centrally symmetric gravitational field, Precession of perihelion of Mercury, Deflection of light, Gravitational lens. Black holes: Schwarzschild black holes, Kruskal space, Black hole thermodynamics. Gravitational waves: Plane waves, Weak field approximation, Gravitational radiation, Transverse-traceless gauge, Electromagnetic analogy. Cosmological constant: Einstein space, de Sitter space, Anti-de Sitter space. Relativistic Cosmology: Thermal background, Hubble expansion, Big bang, Age and density of the universe. Introduction to Friedmann-Robertson-Walker universe.

References:

1. W. Rindler, *Relativity---Special, General, and Cosmological,* Oxford University Press, New York, 2001.
2. C. W. Misner, K. S. Thorne, and J. A. Wheeler, *Gravitation,* Freeman, NewYork, 2000.
3. L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields,* Butterworth Heinmann, 1996.
4. J. V. Narlikar, *Introduction to Cosmology,* Cambridge University Press, New Delhi, 1993.
5. A. Einstein, *The Meaning of Relativity,* Oxford & IBH, 1990.
6. P. A. M. Dirac, *General Theory of Relativity,* Prentice Hall of India, 2001.
7. W. Pauli, *Theory of Relativity,* Dover, 1981.
8. R. P. Feynman, F. B. Moronigo, and W. G. Wagner, *Feynman Lectures on Gravitation,* Addison-Wesley, 1995.
9. S. Wienberg, *Gravitation and Cosmology,* John Wiley, 2004 (Indian Reprinting).

PH-546: String Theory 3-0-0-6

Prerequisites: PH-403, PH-406, PH-501 (Classical Mechanics, Quantum Mechanics II, Electrodynamics II), or equivalent courses.
Short review of basics. Classical mechanics of non-relativistic string. Relativistic string: World sheet, reparametrization invariance, Nambu-Goto action, Polyakov action, boundary conditions and D-branes, static gauge, transverse velocity, motion of open string and points, string wave equation. World sheet currents: conserved currents, momentum current, Lorentz symmetry. Choices for tau and sigma parametrization, mode expansions, light-cone solution. Quantization of relativistic open and closed strings: Light-cone Hamiltonian, string as harmonic oscillator, Virasoro operators, Lorentz generators, state space, photon states, Tachyons and D-brane decay, dilaton and string coupling. D-branes and gauge fields: Open strings on Dp branes, and between parallel branes. T-duality of closed and open strings: winding closed strings, left and right movers, state space of compactified closed strings, T-duality and D-branes, U(1) gauge transformation, Wilson lines. Electromagnetic fields on D-branes. String interactions, Riemann surfaces, Schwarz-Christoffel map, moduli spaces.

Text Book:

1. B. Zwiebach, A First Course in String Theory, Cambridge (2004).

References:

1. K. Becker, M. Becker, and J. H. Schwarz, String Theory and M-Theory, Cambridge (2007).
2. J. Polchinski, String Theory, vols. I and II, Cambridge (1998).
3. M. B. Green, J. H. Schwarz, and E. Witten, Superstring Theory, vols. I and II, Cambridge (1987).

PH 547: Statistical Field Theory 3-0-0-6

Prerequisite: PH-404 Statistical Mechanics (or equivalent)

Thermodynamics of Phase Transitions. Eherenfest's classification. First and second order phase transition. Examples of critical phenomena: liquid-gas, paramagnetic-ferromagnetic, and superfluid transitions. Phase diagrams. Definition of critical exponents. Concepts of scaling, homogeneity, and universality. Partition function: Functional Integral approach, examples. Euclidean field theory. Correlation function and composite operators. Perturbation Theory. Feynman graphs and diagrammatic expansion. Vertex function. Ward-Takahashi identity. Goldstones theorem. Ginzburg criterion. Renormalization in the one- and two-loop approximation. Primitive divergences. Renormalization away from critical point. Relevant and irrelevant operators. Iterative construction of counter terms. Renormalization-group. Callan-Symanzik equation. Fixed points. Scaling and anomalous dimensions. Calculation of critical exponents.

Texts and References:

1. D. J. Amit and V. M. Mayor, *Field Theory, the Renormalization Group, and Critical Phenomena*, World Scientific, 2005.
2. C. Itzykson and J. M. Drouffe, *Statistical Field Theory,* vols. 1 & 2, Cambridge, 1992.
3. G. Parisi, *Statistical Field Theory,* Addison-Wesley, 1988.
4. J. J. Binney, N. J. Dowrick, A. J. Fisher, and M. E. J. Newman, *The Theory of Critical Phenomena,* Clarendon Press, Oxford, 1992.
5. J. Zinn-Justin, *Quantum Field Theory and Critical Phenomena,* Clarendon Press, Oxford, 1996.
6. A.A.Abrikosov, L. P. Gor'kov, and I. Ye. Dzyaloshinskii, Methods of *Quantum Field Theory in Statistical Physics*, 2/e, Pergamon Press, 1965 (Dover reprint).

PH 548: Atomistic Simulation Techniques 2-0-2-6

Molecular Dynamics (MD) Simulation: Interatomic potentials; Pair potentials and many-body potentials; System-size effects and Periodic Boundary Conditions; Equations of motion; Time integration of atomic trajectories; Energy and momentum conservation; Initialization of simulation; Controlling the temperature; Equilibration; Calculation of thermodynamic properties; Simulation of molecular systems; Long range interactions: Ewald summation techniques; Monte Carlo (MC) Simulation: Markov process and Markov chain; Random number generators; Metropolis algorithm; Calculation of thermodynamic properties; Molecular Dynamics simulation in canonical and iso-thermal isobaric ensembles: Nose-Hoover and Parrinello-Rahman methods; Calculation of structural and dynamic properties; Time correlation functions; Calculation of transport coefficients; Error estimation.

Text and References:

1. D. Frenkel and B. Smit, Understanding Molecular Simulation, Academic Press, 1996.
2. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Clarendon Press, Oxford, 1991.
3. J. M. Haile, Molecular Dynamics Simulation: Elementary Methods, John-Wiley & Sons,Inc., 1997.
4. E. A. Jackson, Equilibrium Statistical Mechanics, Dover Publications Inc., 2000.

Lab components:

The lab assignments will involve piece-wise implementation of the theoretical concepts into program units: (i) Generation of simple crystal lattices such as an fcc or bcc lattice. (ii) Assignment of velocities from Maxwellian velocity distributions. (iii) Implementation of periodic boundary conditions. (iv) Implementation of time integrators: Verlet and Gear predictor-corrector schemes. (v) Efficient calculation potential energy and forces between atoms. (vi) Random number generation and quality tests. (vii) Implementation of basic MC moves, and calculation thermodynamic averages. (viii) Calculation of structural properties, such as radial distribution functions. (ix) Calculation of time correlation functions. (x) Calculation of transport coefficients such as self-diffusion coefficient. (xi) Error estimation using block averages.

PH 549: Physics around Compact Objects

Accretion power: Accretion as a source of energy, Black Hole accretors, Radiation from accretion flows; Formation and evolution of accretion-powered binaries; Steady-state accretion disks: Conservation Laws, Source of viscosity, Radial structure of steady-state disks, Shakura-Sunyaev disk; Accretion disk outbursts; High-energy radiation from relativistic accretors; Relativistic outflows: Relativistic beaming, Superluminal motion, Jet formation and collimation; Gamma-ray bursts: Discovery, Properties and Signatures, Models and Constraints; Ultra High Energy Cosmic Rays: Its sources and propagation.

Text and Reference Books:

1. Malcom S. Longair, High Energy Astrophysics, 3rd Ed., Cambridge University Press, 2011.
2. Ulrich Kolb, Extreme Environment Astrophysics, Cambridge University Press, 2010.

3. Juhan Frank, Andrew King, and Derek Raine, Accretion Power in Astrophysics, Cambridge University Press, 2002.
4. Bradley W. Carroll and Dale A. Ostlie, An Introduction to Modern Astrophysics, 2nd Ed., Addison-Wesley, Reading, MA, 2007.
5. Eric Chaisson and Steve McMillan, Astronomy Today, 7th Ed., Benjamin Cummings, 2011.

PH 550: Non-equilibrium Statistical Physics [3-0-0-6]

The course is intended to nurture a preliminary level understanding of dynamics of many-body systems that are out of equilibrium, which generally comes under the umbrella of non-equilibrium statistical Physics, among the undergraduate students. The prerequisite of the course is good understanding of statistical mechanics taught at the undergraduate level. The course will begin with the introduction of necessity of theoretical and phenomenological tools developed to deal with out of equilibrium phenomena while addressing many of the problems in condensed matter Physics, bioPhysics, optics, fluid dynamics, astrophysics, etc. Emphasis will be given to level treatment of time dependent phenomena in various systems. It will be followed by the discussion on setting up a theoretical tool to deal with the stochastic processes. In particular, Brownian motion and many of its application using the Langevin-Equation will be discussed. Subsequently conventional ideas of linear response theory and kinetic theory will be discussed in detail. The general emphasis, however, will be given on the development of generalized Langevin equations for treating nonlinear behaviour in a wide variety of systems. Later part of the course will be devoted to the underpinnings of hydrodynamics of different system and nonequilibrium phase transitions.

Brownian motion:

Introduction to stochastic process, Brownian motion, Langevin equation, Solution of Langevin equation by Fourier transformation, Correlation function and spectral density, The Fokker-Planck equation, Probability flow in the phase space, probability flow for Brownian particle, Application to Brownian motion.

Linear Response Theory:

Linear response theory and the Fluctuation-Dissipation Theorem, microscopic linear response theory and its importance in calculating different transport coefficients, Onsager reciprocal relations.

Kinetic theory:

Derivation of Boltzmann equation and its linear approximation, kinetic theory for two-component Gas, collision operators, derivation of diffusion equation, Eigenfrequencies of the Lorenz-Boltzmann Equation.

Hydrodynamics:

Navier-Stokes Hydrodynamic equations, derivation of mass density, momentum balance and entropy-energy equations, transport coefficients, Linearized hydrodynamical equations and associated transverse and longitudinal modes, superfluid hydrodynamics.

Nonequilibrium Phase transitions:

Non-equilibrium stability criteria, examples of phase stability analysis of different nonlinear system, like chemically reacting system, chemical crystals, Rayleigh-Benard instability.

Texts:

1. L. E. Reichl: A modern course in Statisitical Physics. Wiley-Interscience, New York 1998.

2. Gerd Röpke: Nonequilibrium Statistical Physics. Wiley-VCH, 2013.

3. R. Kubo, M. Toda, and N. Hashitsume: Statistical physics II. Nonequilibrium statistical mechanics. Springer-Verlag, New York 1985.

4. G. Mazenko: Nonequilibrium Statistical Mechanics. Wiley-VCH 2006.

References:

1. C. W. Gardiner: Handbook of stochastic methods for physics, chemistry, and the natural sciences. Springer-Verlag, New York 1985.
2. J. Honerkamp: Statistical physics. An advanced approach with applications. Springer-Verlag, New York 1998.
3. P. M. Chaikin and T. C. Lubensky: Principles of Condensed Matter Physics. Cambridge University Press, 1995.
4. R. Zwanzig: Nonequilibrium Statistical Mechanics. Oxford University Press, 1st Edition 2000.
5. N. G. Van Kampen: Stochastic Processes in Physics and Chemistry. Third Edition, North-Holland Personal Library, 2006.