UNIVERSITY OF THE PUNJAB, LAHORE, PAKISTAN

CURRICULUM OF PHYSICS (2018)

MPhil (2 Years) physics degree program under semester system

DEPARTMENT OF PHYSICS, UNIVERSITY OF THE PUNJAB, LAHORE, PAKISTAN
8/20/2018

MASTER OF PHILOSOPHY (MPhil) PHYSICS DEGREE PROGRAM

Duration of Degree Course	Two years
Teaching System	Semester System
Total Number of Credit Hours	30
Credit Hours for Taught Courses	24 (Semesters I, II)
Credit Hours for Research Thesis	06 (Semesters III, IV)
Session Starts	(Fall) September-October
Eligibility Qualification	BS (Physics) or equivalent
Number of Student Enrollment	25 including all reserved seats

MISSION STATEMENT

The mission of the Master of Philosophy (Physics) program is to equip students with theoretical and applied knowledge of physics for the solutions of complex problems related to understanding of physical world and to enable them to use that knowledge in solving various problems of human world. It is aimed to prepare the students to learn independently and critically in a constantly changing discipline.

OBJECTIVES

The MPhil (Physics) degree course is offered by the Department of Physics as a full-time period of teaching and research and introduces students to research skills and specialist knowledge in the subject of Physics. Main objectives of the program are

- to offer students graduate level courses in theoretical and applied physics
- to give students with relevant experience, the opportunity to carry out research in various disciplines of Physics under close supervision
- to give students the opportunity to develop various skills and expertise relevant to their research interests
- to give students the opportunity to engage in rigorous scholarly pursuit, and to contribute in academic and industrial research
- to prepare students with a theoretical physics background and applied research needed to enter a doctorate program in physics.
- to prepare students to join an appropriate and respectable level position in a physics related field, and to maintain their professional skills in rapidly evolving industry and academia.
- to develope research based scientific thinking and to enhance professional skills for teaching, research, managerial positions in wide range of professions in national and international organizations.

Semester-wise breakup and outline of courses for this program are given as under. In addition to compulsory courses, elective courses of graduate level are offered in various specializations in the subject of Physics. The program meets the standards of international graduate programs in the subject of Physics. Taught courses are offered in semesters I and II, while in semester III and IV, studend work towards their thesis projects. Graduate students are offered research projects from various research groups of the Department. Teaching and Examinations are held according to semester rules of University of the Punjab.

SCHEME OF STUDIES

COURSE CODE KEY

For the course code Phys xxxx, the first letter shows the year of degree course in the university (e.g. for first year course, it is written as 1xxx, for third year course it is 3xxx and for fifth year course it is 5xxx (first year of MPhil course), while second letter represents a number assigned to a specific subject area of physics (e.g. in general classification within the subject of Physics, a number is assigned to a set of similar subject titles i.e. for foundation courses, the number is 0 (Phys x0xx), for classical mechanics and related titles, the number is 1 (Phys x1xx), for electrodynamics and related titles it is 2 (Phys x2xx), for quantum mechanics and related titles, it is 3 (Phys x3xx), for solid state physics and related titles, it is 4 (Phys x4xx), for mathematical physics and related titles, it is 5 (Phys x5xx), for experimental physics and labs, it is 6 (Phys x6xx), for electronics and related titles, it is 7 (Phys x7xx), for materials and nanotechnology, it is 8 (Phys x8xx) etc. The last two letters of the course code show the sequence of the course titles in the specific subject and ranges from 01-99 (e.g. for solid state physics-I offered in third year, course code is Phys 3401 and for solid state physics-II offered in third year, it is Phys 3402, and for solid state physics-III offered in fourth year, code is Phys 4403 etc.).

SCHEME OF STUDIES (MPhil PHYSICS PROGRAM)

	Course Code	Course Title	Credit Hrs.	Course Type
YEAR I	**SEMESTER-I**			
	Phys 5511	Advanced Mathematical Physics	3	Compulsory
	Phys 5611	Experimental Techniques in Physics	3	Compulsory
	Phys	Elective-I	3	Elective
	Phys	Elective-II	3	Elective
	Credit Hrs.		**12**	
	SEMESTER-II			
	Phys	Elective-III	3	Elective
	Phys	Elective-IV	3	Elective
	Phys	Elective-V	3	Elective
	Phys	Elective-VI	3	Elective
	Credit Hrs.		**12**	
YEAR II	**SEMESTER III**			
	Phys 6000	Thesis	3	Research
	Credit Hrs.		**3**	
	SEMESTER-IV			
	Phys 6000	Thesis	3	Research
	Credit Hrs.		**3**	
	Total Credit Hrs.		**30**	

- *Elective courses will be offered from the following list by the Department of Physics in view of avaialability of instructors and related resources.*
- *In semester-I, the students will have to opt both Elective-I and Elective-II courses from the same area of specialization.*
- *In semester-II, the students will have to opt at least three courses from the same area of specialization as those opted in semester-I*
- *In case of two areas of specializations, the number of students in each specialization shall not exceed 60% of the total number of students enrolled in the programs.*

Specialization-1 (Theoretical Physics)			Specialization-2 (Applied Physics)		
Code	**Course Title**	**Cr. Hrs.**	**Code**	**Course Title**	**Cr. Hrs.**
Phys 5111	Nonlinear Physics	3	Phys 5411	Introduction to Condensed Matter Physics	3
Phys 5211	Plasma Physics	3	Phys 5612	Applications of X-Ray Diffraction Method	3
Phys 5112	Classical Field Theory	3	Phys 5711	Physics of Semiconductor Devices	3
Phys 5512	Advanced Computational Physics	3	Phys 5613	Spectroscopy	3
Phys 5311	Quantum Electrodynamics	3	Phys 5412	Introduction to Magnetism and Magnetic Materials	3
Phys 5312	Standard Model of Particle Physics	3	Phys 5413	Lattice Dynamics	3
Phys 5313	Quantum Field Theory	3	Phys 5712	Optoelectronics	3
Phys 5512	Nonlinear Waves and Solitons	3	Phys 5414	Optical Properties of Solids	3
Phys 5212	Advanced Plasma Physics	3	Phys 5415	Superconductivity	3
Phys 5513	Integrable Systems in Mathematical Physics	3	Phys 5811	Nanomaterials (Science, Growth and Characterization)	3
Phys 5314	Advanced Quantum Fied Theory	3	Phys 5316	Applied Nuclear Physics	3
Phys 5315	Supersymmetry	3	Phys 5713	Spintronics, Applications and Devices	3
Phys 5113	General Relativity	3	Phys 5317	Quantum Computing and Information	3
Phys 5514	Group Theory in Physics	3	Phys 5812	Physics of Surfaces and Interfaces	3

(More specializations and course titles in each specialization can be added from time to time subject to the approval by relevant academic bodies)

OUTLINES OF COURSES
COMPULSORY COURSES

Phys 5511	ADVANCED MATHEMATICAL PHYSICS	(CR3)
Preq.	Phys 3503	

Objectives
To demonstrate utility of advanced mathematical techniques in solving problems of physics and to develop working knowledge of Mathematical Physics at graduate level.

Syllabus
Special Functions, Chebyshev Polynomials, Hypergeometric functions, Elliptic functions, Weiersrstrass functions, the Jacobian Elliptic functions, Nonlinear ordinary differential equations (Bernoulli's equation, Riccati equation, Lane-Emden equation, Nonlinear Pendulum, Duffing's equation, Pinney's equation), partial differential equations, orthogonal functions and Fourier series, Boundary-Value Problems in rectangular coordinate systems (separable partial differential equations, classical partial differential equations, Heat equation, Wave equation, Laplace's equation, nonhomogeneous Boundary value problems, Orthogonal series expansions, Fourier Series in two variables, Perturbation theory, Bogoliubov-Krilov method, Nonlinear partial differential equations (Korteweg-de Vries equation, sine-Gordon equation, Liouville equation, Nonlinear Schrodinger equation), Solution of nonlinear partial differential equations, Backlund transformation. Integral equations, Neumann series, Hilbert-Schmidt theory, Calculus of variations, dependent and independent variables, Euler-Lagrange equation and applications, several independent and dependent variables, Lagrange multipliers, variational principle with constraints.

Recommended Books
1. *Mathematical Methods for Physicists, by G. B. Arfken, H. J. Weber and F. E. Harris,(7th Edition), Academic Press, (2012)*
2. *Advanced Engineering Mathematics, by D. G. Zill, (6th Edition), Jones and Bartlett,(2018)*
3. *Mathematical Methods for Physicists: A Concise Introduction, by T. L. Chow, Cambridge, (2000)*
4. *A Course of Modern Analysis, E. T. Whittaker and G. N. Watson Cambridge, (1996).*
5. *A Guide to Mathematical Methods for Physicists,by M. Petrini, G. Pradisi and A. Zaffaroni,World Scientific (2017)*
6. *Mathematics for Physicists, P. Dennery and A. Krzywicki, Dover, (2012)*
7. *Mathematical Methods for Physics and Engineering, K. F. Riley, M. P. Hobson, and S. J. Bence, Cambridge (1999)*

Phys 5611	EXPERIMENTAL TECHNIQUES IN PHYSICS	(CR3)
Preq.	Phys 4404	

Objectives
To learn working principle and instrumentation of experimental techniques which are being applied by experimentalists to characterize materials.

Syllabus
Introduction to characterization methods of solid materials: Solid materials, an overview, growth, bulk characterization, surface characterization, interface characterization, ambient requirements and sample preparation. Experimental Characterization Techniques, optical microscopy, scanning electron

microscopy, transmission electron microscopy, scanning transmission electron microscopy, instrumentations, applications and limitations. Electron Emission Processes, Theory of secondary electron emission, energy distribution of secondary electrons, secondary electron yield, yields measurement methods. Scanning Probe Microscopy, Atomic force microscopy, scanning tunneling microscopy, magnetic force microscopy, working principle, instrumentation, applications and limitations. Auger Electron Spectroscopy (AES): Auger electron emission, instrumentation, depth profiling and interface analysis, applications of AES in material science. X-Ray Photoelectron spectroscopy (XPS), Ultraviolet Photoelectron Spectroscopy (UPS): Introduction, principles, instrumentation, applications, surface and chemical analysis. X-Ray Diffraction: Properties of X-rays, a brief summary, Diffraction of X-rays, experimental methods, crystal structure determination.

Recommended Books

1. *Materials Characterization "Introduction to microscopic and spectroscopic methods" 2nd Ed., by Y. Lang Wiley-VCH, (2013).*
2. *Elements of X-ray Diffraction, B. D. Cullity and S. R. Stock, Prentice Hall, (2003).*
3. *Transmission Electron Microscopy, by D. B William and C. B. Carter, Springer (2009).*
4. *Thin Film Deposition "Principles and Practices" by D. L. Smith, (2009).*
5. *Methods of Surface Analysis, by J. M. Walls, Cambridge, 1988*
6. *Auger Electron Microscopy,* by *H. Bubert, J. C. Rivière and W. S. M. Werner, Wiley–VCH (2011).*
7. *Essentials of Crystallography, by D. Mckie and C. Mckie, Blackwell, (1986).*

ELECTIVE COURSES
SPECIALIZATION-1

Phys 5111	**NONLINEAR PHYSICS**	**(CR3)**
Preq.	**Phys 3501**	

Objectives

To introduce students with basic knowledge of nonlinear dynamical systems and chaos. To develop mathematical problem solving skills related to nonlinear physics.

Syllabus

Nonlinearity and Nonlinear Effects, Breakdown of linear Superposition principle, Forced and unforced nonlinear oscillations, Qualitative Sketch Trial Function (QSTF) method, Examples: Anharmonic Atomic Potential, Small Angle Pendulum, Van der Pol Oscillator, The Duffing Oscillator and nonlinear resonance phenomenon, Autonomous and non-autonomous systems, Phase Space and Phase trajectories, Stability, Attractors and Repellers, Classification of Equilibrium Points, Limit cycles and periodic attractors, Higher dimensional systems, Dynamical flows, Rayleigh Bernard convection and Lorenz model, Bifurcations and onset of Chaos in Dissipative systems, Types of bifurcations, Saddle-node bifurcation, The Pitchfork bifurcation, Transcritical bifurcation, Hopf Bifurcation, Bifurcation Diagram, Fixed Points and Stability of 1-D nonlinear maps, The Logistic Map, Period Doubling, Butterfly Effect and sensitivity to initial conditions(SIC), Universality of Chaos, Feigenbaum numbers, Self Similarity, Lyapunov Exponent and identifying Periodic and Chaotic behaviors, Strange attractor, Fractal character, Fractals in nature, Hausdorff dimension.

Recommended Books

1. *Chaos and Nonlinear Dynamics, by R. C. Hilborn, (2nd Edition), Oxford, (2001)*
2. *Deterministic Chaos, by H. G. Schuster, Wiley-VCH (1995)*
3. *Nonlinear Dynamics, by P. B. Kahn and Y. Zarmi, Dover, (2014)*

4. *Nonlinear dynamics and Chaos, by J. M. Thompson and H. B. Stewart, (2nd Edition), Wiley (2002)*
5. *Nonlinear science: the Challenge of Complex Systems, by Z. Yashida, Springer (2010).*
6. *Nonlinear Dynamics, M. Lakshmanan, S. Rajasekar, Springer, (2002)*
7. *Solving equations with Physical Understanding, J. R. Acton and P. T. Squire, Adam Hilger (1985)*
8. *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering, S. H. Strogatz, Westview Press,(2015)*

Phys 5211	**PLASMA PHYSICS**	**(CR3)**
Preq.	**Phys 4202**	

Objectives
To make students, acquire basic knowledge of plasma physics and its various applications in applied sciences

Syllabus
Introduction to plasma physics, and general properties of plasmas, occurrence of plasmas in nature, concept of temperature, Debye shielding, criteria for plasmas, applications of plasma physics.Single particle motions in plasmas, motion of charged particles in uniform E and B fields, motion of charged particles in non-uniform B and E fields, motion of charged particles in time varying E and B fields, adiabatic invariants. Plasmas as fluids, relation of plasma physics to ordinary electromagnetics, the fluid equation of motion, equation of continuity, the complete set of fluid equations, fluid drifts, plasma approximation. Waves in plasmas, representation of waves, group velocity, plasma oscillations, electron plasma waves, sound waves, ion waves, validity of the plasma approximation, comparison of ion and electron waves, electrostatic electron oscillations perpendicular to B, electrostatic ion waves perpendicular to B, the lower hybrid frequency, EM waves with $B_o = 0$, EM waves perpendicular to B_o, cutoffs and resonances, EM waves parallel to B_o, hydromagnetic waves, magnetosonic waves.

Recommended Books
1. *Introduction to Plasma Physics and Controlled Fusion, by F. F. Chen, (3rd edition), Springer, (2016).*
2. *Fundamentals of Plasma Physics J. A. Bittencourt, (3rd edition), Springer, (2004)*
3. *The Physics of Plasmas, T. J. M. Boyd and J. J. Sanderson, (1st edition), Cambridge (2003)*
4. *Plasma Physics, by A. Piel, (2nd edition), Springer, (2017)*
5. *Plasma Physics and Fusion Plasma Electrodynamics, by A. Bers, Oxford (2018)*

Phys 5112	**CLASSICAL FIELD THEORY**	**(CR3)**
Pre-Reqs	**Phys 3101**	

Objectives
To introduce students with the concept of continuous dynamical systems and field equations. To develop an understanding of electromagnetism as a field theory.

Syllabus
Moving from classical particle mechanics to mechanics of continuous systems, examples Euler Lagrange equations,, the concept of field,classical Lagrangians and Hamiltonians for fields, field equations, canonical formalism and Poisson brackets for fields, variational methods for field theory,

introduction of special relativity and formulation of relativistic classical field theory, four dimensional formulation of fields and the stress-energy momentum tensor, scalar Field. Linear fields and the Klein-Gordon equation, variational method and field equations, Symmetries and conservation laws, Noether theorem, Linear massless scalar fields and the Maxwell field equations, the electromagnetic energy-momentum tensor. Gauge invariance, the Lorenz gauge, charge conservation, four-currents, Canonical stress tensor; conserved, traceless & symmetric stress tensor, Particle and field energy-momentum & angular momentum conservation. The massive vector (Proca) Field, the tensor field, the massless tensor field.

Recommended Books

1. *Principles of Continua with Applications by L. A. Scipio, Wiley, (1969)*
2. *The Classical of Theory of Fields by Laudau, L.D. and Lifshitz, M, Pergamon, (1980).*
3. *Classical Field Theory, by D. E. Soper, Dover, (2008)*
4. *Classical Electrodynmamics by J. D. Jackson, Wiley, (1999).*
5. *Classical Field Theory, J. Franklin, Cambridge (2017)*

Phys 5512	**ADVANCED COMPUTATIONAL PHYSICS**	**(CR3)**
Preq.	**Phys 3504**	

Objectives

To introduce students with advanced methods of computational techniques and simulation methods used in solving problems in the subject of physics

Syllabus

The course will cover topics in advanced MATLAB (or PYTHON or MATHEMATICA) programming based on topics in computational physics involving numerical methods and their application to many physical problems, data processing and expression evaluations, so, the concepts developed in this course will be help for both theoretical and experimental physicists. Advance data visualization, analysis and processing techniques, Improved scalar, vector and matrix manipulation techniques. Improved data presentation, multidimensional data plotting. Dealing with missing data or observations, handing outliers, smoothing and filtering of noisy data, handling heterogeneous data types and storage, data structures. Animations and simulations for 2D and 3D plots. Comparisons of scalars, vectors and matrices by Distance calculations e.g, Euclidean, city block distance etc. Interpolation of multidimensional data, pattern matching, dimension reduction, Eigenvalues and Eigenfunctions, cf-tools and curve fitting, Introduction to advance problem solving techniques in Physics and mathematics, Symbolic differentiation and integration, expansion of diverse series (expression evaluation), advance numerical calculus and differential equations, extension to higher-order equations, ODE solvers. Problem solving and modelling for advance growth and decay problems (radioactivity, charge/current, disease and bacteria etc). Monte-Carlo method and its applications, random walk, diffusion, electron scattering, crystal structure analysis (BCC, FCC etc), atom-atom interactions and interaction potentials, Schrodinger wave equations, Monte Carlo Simulations.

Recommended Books

1. *MATLAB for Engineers by H. Moore, Pearson, (2017)*
2. *MATLAB: An introduction with applications, by A. Gilat, Wiley, (2014)*
3. *Applied Computational Physics, by Joseph F. Boudreau and Eric S. Swanson, Oxford (2018)*
4. *Computational Physics: Simulation of Classical and Quantum Systems (Graduate Texts in Physics), by P. Scherer, Springer, (2013)*

5. *Getting Started with MATLAB: A Quick Introduction for Scientists and Engineers, R. Pratap, Oxford, (2016)*

Phys 5311	**QUANTUM ELECTRODYNAMICS**	**(CR3)**
Preq.	**Phys 4302**	

Objectives
*To acquaint students with quantization of electromagnetic field and to introduce them with techniques used to understand fundamental scattering processes***.**

Syllabus
The electromagnetic field in free space: classical and quantized. The electromagnetic interaction and gauge invariance, the geometry of gauge invariance, the Dyson expansion of the S-matrix and the Wick's theorem, Feynman diagrams in position and momentum space, the Feynman rules of QED and their uses for all possible physical processes in the second order. Scattering of two particles; unpolarized cross-section for the electron-positron to muon-antimuon and the electron-muon scattering, scattering by a static electric field; elastic electron-nucleon scattering and the nuclear form factor, Bremsstrahlung and the infra-red divergence, an introduction to the charge renormalization in QED and the running QED coupling.

Recommended Books
1. *Quantum Field Theory, by F. Mandl and G. Shaw, 2nd Edition, Wiley, (2010).*
2. *Quraks and Leptons, by F. Helzen and A. D. Martin, Wiley, (1984).*
3. *Introduction to Elementary Particles by Griffiths, D., 2nd Edition, Wiley-VCH, (2008)*
4. *Quantum Electrodynamics, by W. Greiner, A. D. Bromley, J. Rienhardt, Springer, (1994).*
5. *Gauge Theories in Particle Physics, by J. R. Aitchison and A. J. G. Hey, Adam Hilger, (1989).*
6. *Quantum Field theory Demystified, by McMahon, D, McGraw- Hill, (2008).*
7. *An introduction to Quatnum Field Theory, Peskin and Schroeder, Addison-Wesley (1995).*
8. *Quantum Electrodynamics, by R. P. Feynman, (Classic Reprint) Forgotten books, (2018)*

Phys 5312	**STANDARD MODEL OF PARTICLE PHYSICS**	**(CR3)**
Preq.	**Phys 4305**	

Objectives
To give an in-depth understanding and mathematical description of fundamental interactions of nature and their unification.

Syllabus
Brief review of relativistic Quantum Mechanics and building blocks of standard model, Gauge Theory of Electroweak Interaction, Gauge symmetry, non-Abelian gauge symmetry, weak interactions, electroweak interactions, spontaneous symmetry breaking, discrete and continuous symmetries, global symmetries and Goldstone's theorem, local symmetries and Higg's mechanism, properties of the Higgs boson, ultraviolet divergences, renormalizability, dimensions of fields and couplings, scattering cross sections, Quantum Chromodynamics Colour and properties of Lie group SU(3), SU(3) gauge symmetry, strong interactions, neutrino masses and oscillations, effective charge and asymptotic freedom, grand unification, supersymmetry.

Recommended Books
1. *Gauge Theories in Particle Physics by I. J. R. Aitchison and A J G Hey, (3rd edition), CRC, (2002).*

2. Modern Elementary Particle Physics, by G. L. Kane, (2nd edition), Cambridge (2017)
3. An Introduction to the Standard Model of Particle Physics, by W.N. Cottingham and D.A. Greenwood, (2nd edition), Cambridge, (2007)
4. Quarks and Leptons, by F. Halzen and A. D. Martin, Wiley, (1984)
5. Concepts in Particle Physics, by V. P. Nair, World Scientific, (2018)
6. Standard Model in Nutshell, by D. Goldberg, Princeton, (2017)
7. The Standard Model: A Primer, C. Burgess and G. Moore, Cambridge, (2006)

Phys 5313	QUANTUM FIELD THEORY	(CR3)
Preq.	Phys 4306	

Objectives
To give an understanding of the concept of second quantization and to introduce basic techniques of quantum field theory used in particle physics.

Syllabus
Review of classical mechanics, lagrangians, variational principle, vibrating stings, classical field theory, Lorentz transformations, Lorentz group, representations of Lorentz group, classical scalar fields, Klein-Gordon equation, complex scalar fields, energy-momentum tensor, electromagnetic field, Maxwell's equations, spinor field, Dirac equation, symmetries and conservation laws, Noether's theorem, translation invariance and conservation theorems. Review of quantum mechanics, canonical quantization of fields, canonical quantization of fields, quantization of scalar fields, particle interpretation of quantum field theory, normal ordering, non-Hermitian fields, conserved charges in quantum field theory. Interacting quantum fields, perturbation theory, time ordering, S-matrix, cross-section, decay rate of an unstable particle, higher order perturbation theory, Wick's theorem, second order perturbation theory, Feynman rules and Feynman diagrams for S-matrix, QED, Feynman rules for QED, renormalization.

Recommended Books
1. *Quantum Field Theory for the Gifted Amateur, by T. Lancaster, S. J. Blundell, Oxford, (2014)*
2. *Quantum Field Theory by L. H. Ryder, (2nd edition),Cambridge, (2013)*
3. *Quantum Field Theory by M. Kaku, Oxford, (1993).*
4. *Quantum Field Theory, by F. Mandl and G. Shaw, 2nd Edition, John Wiley, (2010).*
5. *The Quantum Theory of Fields Vol. I, II by S. Weinberg, Cambridge, (1996).*
6. *Quantum Field theory by M. A. Srednicki, Cambridge (2007).*
7. *An Introduction to Quantum Field Theory, by M. E. Peskin and D. V. Schroeder, Sarat, (2005)*

Phys 5512	NONLINEAR WAVES AND SOLITONS	(CR3)
Preq.	Phys 3503	

Objectives
To give an introduction to nonlinear wave phenomena and to develop mathematical formulation of this phenomena. To give an introduction to waves called solitons.

Syllabus
Basics of linear and non-linear (ordinary and partial) differential equations, superposition principle, Some non-linear equations e.g. non-linear wave equation, non-linear Schrodinger's (NLS) equation, sine-Gordon equation, Liouville's equation, Korteweg-de-vries (KdV) equation, modified KdV

equation, Burger equation, Boussinesq equatio etc. Conservation laws, basic idea, conserved quantities for the KdV equation, Gardner transformation, conservation laws for the sine-Gordon equation. Solutions of non-linear equations, travelling-wave solutions, solitary waves and solitons, Hirota's method (the bilinear form), bilinearization of non-linear differential equations, solutions, of bilinear equations, Backlund transformation, Theorem of Permutability, Backlund transformations for the KdV equation, sine-Gordon equation etc., Riccati equation, Inverse methods, the AKNS scheme, eigen value problem, Lax pairs, Darboux transformation and multi-soliton solutions.

Recommended Books

1. *Backlund and Darboux Transformations, by C. Rogers and W. K. Schief, Cambridge (2003).*
2. *Darboux Transformations in Integrable Systems, by C. H. Gu, H. Hu and Z. Zhou, Springer (2005).*
3. *Nonlinear Partial Differential equations for Scientists and Engineers, by L. Debnath, Birkhauser Boston (1997).*
4. *Solitons: An Introduction, by P. G. Drazin and R. S. Johnson, Cambridge, (1989) 226 P.*
5. *The Direct Methods In Soliton Theory, by R. Hirota, Cambridge, (2004) 200 P.*
6. *Darboux Transformations and Soliton, by V. B. Matveev and M. A. Salle, Springer (1991).*

Phys 5212	**ADVANCED PLASMA PHYSICS**	**(CR3)**
Preq.	**Phys 4202**	

Objectives

To give an introduction to certain advanced techniques used in plasma physics.

Syllabus

Diffusion and mobility in weakly ionized gases, decay of plasma by diffusion, steady state solutions, recombination, diffusion across a magnetic field, collisions in fully ionized plasmas, the single-fluid MHD equations, diffusion in fully ionized plasmas, solutions of the diffusion equation, Bohm diffusion and neoclassical diffusion. Equilibrium and stability - introduction, hydromagnetic equilibrium, the concept of β, diffusion of magnetic filed into a plasma, classification of instabilities, two-stream instability, the "Gravitational" instability, resistive drift waves, the Weibel instability. Kinetic theory, the meaning of , equations of kinetic theory, derivations of fluid equations, plasma oscillations and Landau damping, a physical derivation of Landau damping, ion Landau damping, kinetic effects in a magnetic field. Nonlinear effects – introduction, sheaths, ion acoustic shock waves, the pondermotive force, parametric instabilities, plasmas echoes, nonlinear Landau damping, equations of nonlinear plasma physics.

Recommended Books

1 *Introduction to Plasma Physics and Controlled Fusion, by F. F. Chen, (3rd edition), Springer, (2016).*
2 *Fundamentals of Plasma Physics, J. A. Bittencourt, (3^{rd} edition), Springer, (2004)*
3 *The Physics of Plasmas, T. J. M. Boyd and J. J. Sanderson, (1^{st} edition), Cambridge (2003)*
4 *Plasma Physics, by A. Piel, (2^{nd} edition), Springer, (2017)*
5 *Plasma Physics and Fusion Plasma Electrodynamics, by A. Bers, Oxford (2018)*

Phys 5513	**INTEGRABLE SYSTEMS IN MATHEMATICAL PHYSICS**	**(CR3)**
Preq.	**Phys 3101**	

Objectives

To enable students understand basis theory of integrable classical dynamical systems and to use mathematical methods in order to analyse such systems.

Syllabus

Hamiltonian formalism, Poisson structure, Hamiltonian systems, Integrability of a Hamiltonian system (Liouville integrability), Dynamical systems of classical mechanics, Harmonic oscillator, Action-angle variables, examples of integrable models solved by Liouville theorem, Kepler two-body problem, rigid body, systems with closed trajectories. Korteweg-de Vries (KdV) equation, KdV equation as a Hamiltonian systems, properties of the KdV solutions, conserved quantities, Miura transformation, Integrability of the KdV equation, higher order equations of hierarchy, involution of conserved quantities, Initial value problem for the KdV equation, Inverse scattering theory in one-dimension, action-angle variables for the kdV equation.
Lax representation, Lax representation with a spectral parameter, Zakharov-Shabat formulation, zero-curvature method.

Recommended Books

1. *Integrable Models, by A. Das,World Scientific (1989)*
2. *Basic methods of soliton theory, by I. Cherednik, "Adv. Ser. Math. Phys. 25 (1996) 1-250.*
3. *Hamiltonian Methods in the Theory of Solitons, by L. D. Faddeev and L. A. Takhtajan, Springer, (1987).*
4. *Introduction to Classical Integrable Systems, by O. Babelon, D. Bernard, M. Talon, Cambridge, 2008.*
5. *Theory of Solitons: The Inverse Scattering Method by S. Novikov, S. V. Manakov, L. P. Pitaevsky and V. E. Zakharov, " (Contemporary Soviet Mathematics), Consultants Bureau, (1984).*

Phys 5313	**ADVANCED QUANTUM FIELD THEORY**	**(CR3)**
Preq.	**Phys 4305**	

Objectives

To introduce path integral quantization of fields and advanced methods of quantum field theory in particle. physics

Syllabus

Path Integral Quantization, Quantum field theory and functional integration, path integral quantization, scalar field theory, Green function, S-matrix, Lehmann-Symanzik-Zimmereman reduction, perturbation theory, Wick's theorem, Feynman rules for phi^4 theory, spectral representation., Renormalization, regularization, BPH renormalization, renormalization group, Callan-Symanzik equation, asymptotic freedom. Gauge theories, abelian and non-abelian theories, quantization of gauge theories, gauge fixing and Faddeev-Popov quantization, integration over Grassman variables, Berezin rules, Feynman rules for Quantum Chromodynamics (QCD), renormalization of QCD.

Recommended Books

1. *Quantum Field Theory for the Gifted Amateur, by T. Lancaster, S. J. Blundell, Oxford, (2014)*
2. *Quantum Field Theory by L. H. Ryder, (2nd edition),Cambridge, (2013)*
3. *Quantum Field Theory by M. Kaku, Oxford, (1993).*
4. *Quantum Field Theory, by F. Mandl and G. Shaw, 2nd Edition, John Wiley, (2010).*
5. *The Quantum Theory of Fields Vol. I, II by S. Weinberg, Cambridge, (1996).*
6. *Quantum Field theory by M. A. Srednicki, Cambridge (2007).*

7. *An Introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder, Sarat, (2005)*

Phys 5315	**SUPERSYMMETRY**	**(CR3)**
Preq.	**Phys 4305**	

Objectives
To acquaint students with the transformation of fermions and bosons and the algebra behind this transformation and its applications in particle physics.

Syllabus
Supersymmetry, symmetries, No-go theorem, Clifford Algebra and spinors, Dirac and Majorana spinors, supersymmetry algebra, superfields, vector superfields, 4D SUSY Lagrangians, Wess-Zummiw Lagrangian, 2D supersymmetry, 2D supersymmetic models, SUSY transformations on fields 2D examples, BPS solitions in d=2, central charges and BPS solutions, Extended supersymmetry, supersymmetry breaking, Grand unification schemes in terms of group theory, supersymmetry in particle and condensed matter physics, minimal supersymmetric standard model (MSSM) and related topics.

Recommended Books
1. *Supersymmetry and String Theory, by M. Dine, Cambridge, (2016)*
2. *Supersymmetry Demstified by P.Labelle, McGraw Hill (2009).*
3. *Supersymmetry by P.M.R.Binetruy, OUP, (2007).*
4. *Supersymmetry and Supergravity by J.Wess and J.Bagger Princeton (1992).*
5. *Modern Supersymmetry: Dynamics and Duality by J.Terning, OUP (2009).*
6. *Supersymmetry, supergravity and unification, by P. Nath, Cambridge, (2016)*
7. *Introduction to Supersymmetry by J.W. Muller-Kirster and A.Wiedemann World Scientific (2010).*

Phys 5113	**GENERAL RELATTIVITY**	**(CR3)**
Preq.	**Phys 4102**	

Objectives
To familiarize students with fundamental principles and mathematics of general theory of relativity.

Syllabus
The curved space time of general relativity: testing of equality of gravitational and inertial mass, equivalence principle, geodesics, metric coordinate transformations, Christoffel symbols, geodesics and coordinate transformations. The physics and geometry of geodesics: geodesic equation from variational principle, from Einstein equivalence principle to the principle of general covariance, tensor algebra, the covariant derivative of vector fields, parallel transport and geodesics, generalizations. Physics in a gravitational field: particle mechanics and electrodynamics in a gravitational field, conserved quantities from covariantly conserved currents and tensors. Lie derivatives, symmetries and Killing vectors: symmetries of a metric, the Lie derivative for scalars, vector fields, tensor fields, metric and Killing vectors. Riemann curvature tensor, parallel transport, geodesic derivative equations, Einstein equations, Bianchi identities, cosmological constant, Weyl tensor, Einstein-Hilbert action, the matter Lagrangian and consequence of the variational principle. Tests of general relativity, black holes, relativistic star models, cosmological models, early stages of evolution of the universe, gravitational waves.

Recommended Books

1. *Gravity: an Introduction to Einstein's General Relativity, by J. B. Hartle, Addison-Wesley, (2003)*
2. *Space-Time and Geometry: An Introduction to General Relativity, by S. Caroll, International Edition, Pearson, (2016).*
3. *Gravitation and Cosmology, by S. Weinberg, Wiley, (1972).*
4. *A First Course in General Relativity, by B. Schutz, (2nd edition), Cambridge, (2009)*
5. *Introduction to General Relativity and Cosmology, by C. G. Bohmer, World Scientific (2016)*
6. *Introduction to General Relativity, by C. Bambi, Springer, (2018)*

Phys 5514	GROUP THEORY IN PHYSICS	(CR3)
Preq.	Phys 3501	

Objectives
To give an introduction to fundamental methods of group theory used in various areas of physics especially particle physics.

Syllabus
Elements of group theory; Normal subgroups; Quotient groups; Law of transformations; Homeomorphism and isomorphism, Matrix Lie groups, exponential map, examples SO(3) and SU(2), Lorentz group and Poincare' group, Lie algebras, reducible and irreducible representations, Direct sums and tensor product, ideals, Killing form Classification of finite-dimensional. Algebras, Cartan subalgebra, Cartan-Weyl basis, Dynkin Ddiagrams, Weights and roots, comples semi-simple Lie algebras. applications in Physics. Matrix representations of generators of SU(2) and SU(3), roots of SU(2) and SU(3), weights of various representations of SU(2) and SU(3); Young's tableaux and irreducible representations of the permutation group, SU(2) and SU(3); decomposition of the product of irreducible representations; Clebsh-Gordan coefficients; eightfold way; quark model; flavour, spin and colour wave functions of quark antiquark and three quark systems.

Recommended Books
1. *Group Theory, A Physicist's Survey, P. Ramond, Cambridge, (2010)*
2. *Group and Representation Theory, by J. D. Vergados, World Scientific (2016)*
3. *Group Theory in a Nutshell for Physicists, by A. Zee, Princeton (1916)*
4. *Symmetries and Conservation Laws in Particle Physics, by S. Haywood, Imperial (2010)*
5. *Lie Groups and Lie Algebras for Physicists, by A. Das, S. Okubu, World Scientific, (2016*

ELECTIVE COURSES
SPECIALIZATION-2

Phys 5411	INTRODUCTION TO CONDENSED MATTER PHYSICS	(CR3)
Preq.	Phys 4405	

Objectives
To equip students with understanding basic principles of condensed matter theory and its applications in physics and technology.

Syllabus
Crystals: Bloch theorem and band structure methods: Crystal and reciprocal space, Brillouin zone, X-ray diffraction, Independent particles in periodic potential, Bloch's theorem, nearly free electron and tight binding methods, Periodicity and gap openings. Hartree and Hartree-Fock (HF) theories : The variational approach, HF equations, ionization potential and electron affinity, shortcomings of HF.

Density Functional Theory: variational formulation, LDA exchange and correlation in the electron gas. Thomas-Fermi theory: Kinetic energy functionals, finite temperature generalization, linear TF screening, linear response and Lindhard static susceptibility. Collective Quantum Phenomena in Condensed Matter: Collective modes, Correlation functions and response functions, response of independent electron gas, electron-phonon interaction, Ginzburg-Landau theory of phase transition, polarons, metal-insulator transitions, Wigner crystal, superconductivity, pairing and elementary BCS theory, Josephson effect.

Recommended Books

1. *Condensed Matter Physics by M. P. Marder, Wiley, (2000).*
2. *Solid State Physics: an introduction to principles of materials science by H. Ibach, and H. Luth, Hans, 4th Ed: Berlin, Springer (2009)*
3. *Solid State Physics, by N. W. Ashcroft and D. Mermin, Brooks Cole, (1976), Thomson (India) (2003).*
4. *Introduction to Solid State Physics, by C. Kittel, Wiley,7th Edition, (1996).*
5. *Solid State Physics, by G. Grasso and G. P. Parravicini, Academic Press (2013).*
6. *Advanced Condensed Matter Physics, by L. M. Sander, Cambridge (2009).*

Phys 5612	APPLICATIONS OF X-RAY DIFFRACTION METHOD	(CR3)
Preq.	Phys 3401	

Objectives

To teach students to learn practical aspects of powder and single crystal X-ray diffraction methods, including the determination and refinement of crystal structures.

Syllabus

Basics of crystallography: Crystal symmetry, symmetry operations, point groups, plane groups and space group, principles of X-ray diffraction, geometry of X-ray diffractometer, instrumentation, diffraction pattern, structure refinement, least-squares, Debye-Waller factor, Rietveld analysis, the March-Dollase approach, single and powder crystal diffraction methods, single crystal diffractometer, powder diffractometer, limitations of uses, recording powder diffraction pattern, qualitative and quantitative phase analysis, integrated intensities, various factors effecting shape of intensity peaks, crystal structure determination, systematic shift in peak positions, lattice parameter determination for crystal systems, Scherrer method, particle size determination, residual stress measurements through X-ray diffraction, pole figures and rocking curves, limitations of X-ray diffraction technique, Synchrotron radiation, dipole radiation, insertion devices, synchrotron radiation and X-ray flourescence analysis, metal-semiconductor interface study by X-ray synchrotron radiation, hard and soft X-ray synchrotron radiation, pair distribution function, nuclear resonant scattering, imaging the magnetic spin structure of magnetic layers, X-ray reflectivity at interfaces, synchrotron tomography.

Recommended Books

1. *Basics of X-ray Diffraction and its Applications, by K. R. Hebbar, I.K. Int. Pub. House, (2007).*
2. *Fundamentals of Crystallography by C. Giacovazzo (Eds.), Oxford, (2nd edition) (2002).*
3. *Elements of X-Ray Diffraction by B. D. Cullity; Addision-Weseley, (1978).*
4. *X-Ray Diffrcation Procedures by H. P. Klug and L. E. Alexander; Wiley (1976).*
5. *X-Ray Crystallography by M. J.Buerger Krieger Publishing Company; Reprint edition, (1980).*
6. *X-Ray Diffraction: Modern Experimental Techniques, by O. H. Seeck and B. Murphy, Pan Stanford, (2015)*

7. *Structure determination by X-ray crystallography by M. Ladd and R. Palmer, Springer (2013)*

Phys 5711	PHYSICS OF SEMICONDUCTOR DEVICES	(CR3)
Preq.	Phys 3402	

Objectives
To give students an introduction to major developments in semiconductor devices and their application in science and technology

Syllabus
Semiconductor Material and Device Fabrication: Silicon and other semiconductors as device materials; crystal structure, energy bands, statistics, Fermi level, carrier concentration at thermal equilibrium, carrier transport phenomena, Hall effect, recombination, basic properties for semiconductor operation. Effect on carrier lifetime and mobility; bulk crystal growth; crystal characterization, epitaxial growth, with molecular beam epitaxy and multiplayer structures, Dopants and Doping techniques with their limits of solubility; Ion implantation and diffusion doping, thermal oxidation, dielectric layer deposition, metallization, wet and dry etching, optical and next-generation lithographic methods, CMOS Process. Devices and Circuits: FET devices and theory; MOSFET; accumulation, depletion and inversion modes, enhancement and depletion modes of operation; n-and p-channel devices; I-V operating relations in active and saturation regions, threshold voltage, Metal-Semiconductor Contacts: equilibrium, idealized metal semiconductor junctions, nonrectifying (ohmic) contacts, Schottky diodes, tunneling. Metal-Oxide-Silicon System: MOS structure, capacitance, oxide and interface charge (charging of traps, tunneling through oxide). NMOS and CMOS inverters.

Recommended Books
1. *Physics of Semiconductor Devices, J. P. Colinge and C. A. Colinge, Springer (2005).*
2. *Semiconductor Physics and Devices: Basic Principles by D. A. Neaman, McGraw-Hill, (4th Ed.), (2012).*
3. *Semiconductor Device Fundamentals by R. F. Pierret, Addison- Wesley, (1996)*
4. *Physics of Semiconductor Devices by S. M. Sze, Wiley, (3rd Edition), (2008).*
5. *Semiconductor Devices, Physics and Technology, by S. M. Sze and M. K. Lee, Wiley, (3rd Ed.), (2012).*

Phys 5613	SPECTROSCOPY	(CR3)
Preq.	Phys 4404	

Objectives
The objective of this course is to learn working principle and instrumentation of spectroscopy techniques to appy for spectroscopic analysis of variety of materials.

Syllabus
Spectroscopic techniques: Nature of excitations, excitation measuring methods, signal measurement process, absorption spectroscopy, fluorescence spectroscopy, X-ray absorption spectroscopy, flame emission spectroscopy, UV/VIS spectroscopy, FTIR spectroscopy, laser spectroscopy, NMR spectroscopy, mass spectroscopy, atomic absorption (AA) spectroscopy, attenuated total reflection (ATR) and Raman spectroscopy. Sample preparation techniques: Sample preparation for spectroscopy analysis, limitations for materials in solid, liquid and thin film form, In addition to the established KBr pellet technique, systematic experimental comparison of different techniques, mutual advantages and

applications, Nondestructive method for determination of molecular conformation, determination of molecular orientation.

Recommended Books

1. *Modern Spectroscopy by J. M. Holass, Wiley, (2004).*
2. *Introduction to Spectroscopy, D. L. Pavia and G. M. Lampman, Cengage, (2014)*
3. *Handbook of High-Resolution Spectroscopy, by M. Quack (Editor), F. Merkt, Wiley (2009).*
4. *Laser Spectroscopy by W. Demtröder, 3rd Ed. (Springer, 2003).*
5. *IR and Raman Spectroscopy: Fundamental Processing by S. Wartewig, Wiley-VCH (2003).*
6. *Fundamentals of Fourier Transform Infrared Spectroscopy by B. C. Smith, CRC (2011).*

Phys 5412	**INTRODUCTION TO MAGNETISM AND MAGNETIC MATERIALS**	**(CR3)**
Preq.	**Phys 4406**	

Objectives

To introduce students magnetic materials their properties, processing and applications

Syllabus

Categories of materials on the basis of response to applied magnetic field, Origin of electronic magnetic moments, Atomic origins of magnetism, Classical and quantum phenomenology of paramagnetism, Derivation of expression for paramagnetic susceptiblity, temperature independent paramagnetism. Derivation of diamagnetic susceptibility, Meissner effect showig perfect diamagnetism, Weiss molecular field theory of ferromagnetism, origin of Weiss molecular field, collective-electron theory of ferromagnetism, natur and types of magnetic domains, types of walls separting domains, Barkhausen effect, Weiss-theory of antiferromagnetism, study of antiferromagntism using neutrons, temperature dependence of magnetic susceptibility, negative molecular field, Weiss theory of ferrimagnetism, temperature dependent magneization in ferrites and garnets, stucture dependent magnetic anisotropy, origin of magnetocrystalline anisotropy, shape and stress anisotropy, magnetostriction, Imaging of the magnetic domains, magnetism in thin films and nanoparticles, exchange bias effect, magneto-optics, magnetic semiconductors and insulators, Jahn-Teller distortions, magnetoresistivity, multiferroics, magnetoelectric effect.

Recommended Books

1. *Introduction to Magnetic Materials, by B.D. Cullity and C.D. Graham, Wiley-IEEE, (2008).*
2. *Magnetism and Magnetic Materials, J. M. D. Coey, Cambridge (2010).*
3. *Magnetic Materials: Fundamentals and Device Applications, by N.A. Spaldin, Cambridge, (2011).*
4. *Magnetism: Fundamentals, by L. Etienne et al, Springer (2004).*
5. *Physics of Magnetism and Magnetic Materials, by K.. H. J. Buschow and F.R. de Boer, Springer (2003).*
6. *Magnetism in Condensed Matter, by S. Blundell, Oxford, (2001).*
7. *Modern Magnetic Materials: Principles and Applications, by R. C. O' Handley,Wiley (1999).*
9. *Introduction to Magnetism and Magnetic Materials, CRC Press (3rd edition), (2015).*

Phys 5413	**LATTICE DYNAMICS**	**(CR3)**
Preq.	**Phys 4404**	

Objectives

To engage students in understanding dynamics of lattices and its implications in understanding various properties of solids

Syllabus

Born Oppenheimer approximation, Adiabatic approximation, Harmonic approximation, Normal modes, Bose Einstein distribution function, Experimental methods - Neutron diffraction, Phonon dispersion curves, Linear monatomic lattice, Linear diatomic lattice, Nearest neighbour force constants, Acoustical and Optical phonons, 2-D square lattice, Dynamical matrix, Transverse and Longitudinal phonon modes, Simple cubic lattice, Dynamical matrix , bcc and fcc lattice, Density of states, Debye and Einstein model, Specific heat at high and low temperature, Optical absorption due to phonons, Phonon-phonon interactions, Electron-phonon interactions, Mathematica Computer Demonstrations, Dispersion relations & Density of States, Normal modes pattern of vibrations, Linear monatomic lattice, Linear diatomic lattice, Monatomic square lattice, BCC monatomic lattice, Einstein & Debye Model, Bose-Einstein distribution function, Specific Heat, InfraRed Photon Absorption - Restrahlen region, Dielectric Constant, Refractive Index, Reflectivity, Absorption Coefficient, Polariton.

Recommended Books

1. *Phonons and Polaritons, Interaction of radiation with condensed matter, by R. F. Wallis, IAEA, (1977)*
2. *Introduction to Lattice Dynamics, by M. T. Dove, Cambridge, (2005)*
3. *Quantum Phenomena Modular Series on Solid State Devices, by S. Datta, Addison Wesley (1989)*
4. *Introduction to Solid State Physics, C. Kittel, Wiley, (2004).*

Phys 5712	**OPTOELECTRONICS**	**(CR3)**
Preq.	**Phys 3702**	

Objectives

To intdoduce students with fundamental concepts of optoelectronics and photonics

Syllabus

Photonic devices**,** Radiative transitions and optical absorption, semiconductors materials for opto electronics, visible LEDs, infrared LEDs, organic LEDs, Semiconductor Laser; Laser materials, Laser operating characteristics, carrier and optical confinement, optical cavity and feedback, distributed feedback Lasers and quantum-well Lasers, Photodectors, potoconductor, phtodiodes, mtal-smiconductor, hterojunction, photodiode and phototransistors; photoconductor, quantum efficiency and response speed, Avalanche photodiode.

Solar Cells, Semiconductor and polymer solar cells, solar radiations and ideal conversion efficiency, p-n junction solar cell, amorphous and compound-semiconductor solar cells, interface and then film solar cells, optical concentration to reduce cost, optical fiber sensor, CCD, optical information and processing, optical computing.

Recommended Books

1. *Fundamental of Photonics by B. E. A. Saleh and M. C. Teich, Wiley, (1991)*
2. *Optoelectronics and photonics, by S. O. Kasap, Pearson (2012)*
3. *Fiber Optic Communication Systems by G. P. Agarwal, Wiley, (1992)*
4. *Optoelectronics, J. Wilson and J. Hawkes, Pearson (2017)*
5. *Lasers and Optical Engineering by P. Das, Springer, (1991).*
6. *Laser and Electro-Optics, C. C. Davis, Cambridge, (1996).*
7. *Optical Computing by M. A. Karim and A. A. Awwal, John Wiley, (1992).*

8. *Optical Fiber Communication, G. Keiser, 3rd Edition, McGraw Hill, (2000).*

Phys 5414	**OPTICAL PROPERTIES OF SOLIDS**	**(CR3)**
Preq.	**Phys 4404**	

Objectives
To engage students in understanding optical properties of materials and related applications.

Syllabus
Classification of optical processes, optical coefficients, Absorption and Reflection, Complex refractive index and dielectric constant, optical materials, microscopic models, classical propagation of light in optical medium, the classical dipole oscillator model, interband optical transitions, transition probability from time dependent perturbation theory, wavevector conservation and parity selection rules, joint density of states, direct and indirect transitions, excitons, Wannier-Mott excitons – hydrogenic model, Exciton-Polariton, Frenkel excitons, low-dimensional systems, effect of confinement on the joint density of states, quantum well with infinite potential barriers: selection rules and band structure modifications, effect of confinement on excitons, optical response of an electron gas, dipole oscillator model for the free electron gas, AC conductivity, low/high-frequency regime, reflectivity from alkalis, transition metals and doped semiconductors, plasmons, optical studies of phonons, harmonic oscillator model for a linear chain of ions, lattice-response in the low-damping limit: Lyddane-Sachs-Teller relationship and Reststrahlen band, measurement of and examples for lattice reflectivity spectra, phonon-polariton, inelastic light scattering: Raman/Brillouin scattering, experimental details and examples, phonon lifetimes, optics of anisotropic media, electric susceptibility tensor, propagation of electromagnetic waves in an isotropic medium, ordinary and extraordinary rays in uniaxial crystals, refractive index ellipsoid.

Recommended Books
1. *An Introduction to Solid State Physics and its Applications, Elliot & Gibbson, MacMillan (1976).*
2. *Introduction to Solid State Physics by C. Kittle (7th edition) Wiley, (1996).*
3. *Quantum Theory of the Optical and Electronic Properties of Semiconductors, by H. Haug and S.W. Koch, 4th ed. World Scientific, (1993).*
4. *Optical Properties of Solids, M. Fox, Oxford, (2001).*
5. *Optical Characterization of Solids, D. Drogman, Springer, (2002).*
6. *Optical Properties of Solids, by K. Locharoenrat, Pan Stanford, (2016)*
7. *Solid State Properties, by M. Dresselhaus and G. Dresselhaus, Springer, (2018).*

Phys 5415	**SUPERCONDUTIVITY**	**(CR3)**
Preq.	**Phys 4405**	

Objectives
To provide the student with a working knowledge of superconductivity from an experimental point of view, both with respect to the mathematical understanding and physical application.

Syllabus
Discovery, zero resistance and critical temperature, magnetization, perfect diamagnetism, meissner effect, trapped flux, type I and II behaviour, superconducting elements and compounds, cuprate superconductors, structures and preparation, doing phase diagram, superconducting state, pair state, effective wave function, time and space dependence of the phase, Aharonov Bohm effect, London equations, penetration depth, flux quatisation, gauage invariance. Electrodynamics of

superconductors, London's model, flux quantization, Josephson Junctions, superconducting quantum devices, equivalent circuits, high-speed superconducting electronics, and quantized circuits for quantum computing. The course also provides an overview of type II superconductors, critical magnetic fields, pinning, the critical state model, superconducting materials, and microscopic theory of superconductivity, Ginzburg-Landau description of superconductivity, coherence length, the magnetic penetration depth, the distinctions between Type-I and Type-II superconductors, flux quantization, and the Josephson effects, leading to two important superconducting devices, the Josephson junction and the SQUID.

Recommended Books

1. *Superconductivity: An Introduction, by R. Kleiner and W. Buckel, Wiley-VCH, (2016)*
2. *Superconductivity, by C. P. Poole Jr. and H. A. Farach, Elsevier, (2014)*
3. *Introduction to Superconductivity by M. Tinkham, Dover, (2004).*
4. *Physical Propterties of High-Temperature Superconductors by D. M. Ginsberg (ed), World Scientific.*

Phys 5811	**NANOMATERIALS (SCIENCE, GROWTH AND CHARACTERIZATION)**	**(CR3)**
Preq.	**Phys 4405**	

Objectives

To provide students witt knowledge and the basic understanding of nanotechnology and nanomaterials

Syllabus

Nanomaterial science, Historic Developments, Classification of Nano materials, nanotechnology in classic art works, Quantum confinement, relevant length scale, Feynman talk on small structures, Nano scale dimension, Moore's law and the SIA road map. Nanomaterials with unconventional electronic properties, Density of states in 3-D (bulk), 2-D (quantum well), 1-D (nanowires) and 0-D (quantum dots) structures, Correlated Electron systems, Oxide hetrostructures, 2D physics at interfaces, temperature vs. composition phase diagrams, Carbon based materials, graphene and carbon nanotubes. Growth: Introduction to nanomaterials processing, Nano particle synthesis, top-down vs bottomup approach, Fabricating nano structures (thin films), Choise of substrate, Epitaxy and growth modes, stresses in thin films, Physical Vapor Deposition (PVD) Methods for growth of thin films, molecular beam epitaxy (MBE), Sputtering, Pulsed lased deposition (PLD), a brief survey of other methods, Device fabrication. Characterization: Reflection High-Energy Electron Diffraction (RHEED), Optical characterizations, Electrical characterizations, Magnetic characterizations. Nanomaterials applications (selected): Fundamental and industrial, Nanomaterials as drug carriers, Single electron transistor (SET).#

Recommended Books

1. *Understanding Nanomaterials, by M. S. Johal and L. E. Johnson, (2nd Edition), CRC, (2018)*
2. *Nano-age: how nanotechnology changes our future, by M. Pagliaro, Wiley, (2011).*
3. *Introduction to Nanoscience and Nanotechnology, by C. Binns, Wiley, (2010)*
4. *Introduction to Nanoscience, S. Lindsay, Oxford, (2009).*
5. *Nanophysics and Nanotechnology, by E. L. Wol, (2nd edition) Wiley-VCH , (2006)*
6. *Nanomaterials Hand book, Y. Gogotsi, CRC, (2006).*
7. *Handbook of Deposition Technologies for Films and Coatings: Science, Applications and Technology, by P. M. Martin, (3rd edition), William Andrew, (2009)*
8. *Carbon Materials and Nanotechnology, by A. Krüge , Publisher Wiley VCH, March (2010.)*
9. *Introduction to Nanotechnology, by C. Poole Jr., F. J. Owens, Wiley, (2003)*

Phys 5316	APPLIED NUCLEAR PHYSICS	(CR3)
Preq.	Phys 4304	

Objectives
To communicate knowledge of basic techniques which exploit nuclear particles, and to develop an understanding of the underlying physics and applications.

Syllabus
Neutron Physic, the interaction of neutrons with matter in bulk, thermal neutrons, cross-section (measurement of total cross-section), diffusion theory, Fermi age equation. Quantum mechanical calculations of deuteron bound-state wave function and energy; n-p scattering cross section; transition probability per unit time and barrier transmission probability. It also covers binding energy and nuclear stability; interactions of charged particles, neutrons, and gamma rays with matter. Nuclear Energy Sources: Nuclear fission as a source of energy, four factor formula, the chain reacting system, the neutron cycle, critical dimensions of a thermal nuclear reactor, the calculation of the multiplication constant for a homogeneous thermal reactor, the heterogeneous thermal reactor, energy production in stars, thermonuclear reactions, CNO and P-P cycle in detailed, controlled thermonuclear reactions and fusion reactor, age of galaxy. Radioactive Measurement and Tracer Techniques: Energy measurement, coincidence measurements, time resolution, measurement of nuclear life times, trace element analysis, mass spectrometry with accelerators.

Recommended Books
1. *Introductory Nuclear Physics by K. S. Krane, Wiley, (2008).*
2. *Nuclear Physics in a nutshell, by C.A. Bertulani, Princeton, (2007).*
3. *Nuclear Physics by A. Kamal, Springer, (2014)*
4. *Foundations of Nuclear and Particle Physics, T. W, Donnelly and J. A. Formaggio, Cambridge (2017)*
5. *Theoretical Nuclear Physics by Blatt and Weisskopt Dover, (1991).*

Phys 5713	SPINTRONICS, APPLICATIONS & DEVICES	(CR3)
Preq.	Phys 4406	

Objectives
To make students understand basic principles and applications of spintronic devices.

Syllabus
Histrorical Development: Two spin cahnnel model, Spin Asymmetry, Spin Accumulation, Spin Diffusion Length, Two Terminal Spinelectonics, Spin Tunneling Process, Three Terminal Spinelectronics, Meso Megnetism, Dominwall in Spin Electronics, Hybrid electonics, Spin Transport in semi conductors, Direct Spin Injection, Spin Blockade. Coupling of Electron Spins to Nuclear Spins: Nuclear spin in a strong magnetic field, magnetic interactions and magnetic couplings, coupling mechanisms. Conservation of spin angular momentum, photochemical reaction mechanisms, spin polarization of the triplet state, spinomers, the dynamic radical pair, magnetic effects on chemical reactions, the magnetic isotope effect on radical pair reactions, electron spin, electron intrinsic angular momentum, electron spin magnetic moment, nano magnetic arrays.

Recommended Books
1. *Concepts in spin Electronics, by S. Maekawa, Oxford, (2006).*
2. *Introduction to Spintronics, S. Bandyopadhyay and M. Cahay, CRC (2015).*

3. *Spin Physics in semiconductor by Mikhail I. Dyakonov, Springer, (2008.)*
4. *Spintronics Vol.82 by T. Dietl, Wiley, (2010).*
5. *Spintronics Materials, Applications and Device, by C. Giulia, Lombardi and Ginerva, Nova (2009).*
6. *Nanomagnetism and Spintronics, by T. Shinjo, Elsevier, (2013)*

Phys 5317	**QUANTUM COMPUTING & INFORMATION**	**(CR3)**
Preq.	**Phys 4302**	

Objectives

To introduce students to the basics of the quantum model of computation and information theory.

Syllabus

Computer technology and historical background, Basic principles and postulates of quantum mechanics: Quantum states, evolution, quantum measurement, superposition, quantization from bits to qubits, operator function, density matrix, Schrodinger equation, Schmidt decomposition, EPR and Bell's inequality, Quantum Computation: Quantum Circuits, Single qubit operation, Controlled operations, Measurement, Universal quantum gates, Single qubit and CNOT gates, Breaking unbreakable codes: Code making, Trapdoor function, One time pad, RSA cryptography, Code breaking on classical and quantum computers, Schor's algorithm, Quantum Cryptography: Uncertainty principle, Polarization and Spin basis, BB84, BB90, and Ekert protocols, Quantum cryptography with and without eavesdropping, Experimental realization, Quantum Search Algorithm.

Recommended Books

1. *Quantum Computation and Quantum Information by M. A. Nielson and I. L. Chuang, Foundation Books, (2007).*
2. *Exploration in Quantum Computation, by C. P. Williams and S. H. Clearwater, Springer, (2nd ed.) (2011).*
3. *The Physics of Quantum Information, P. Bouwmester, A. Ekert, and A. Zeilinger, Springer, (2010).*
4. *Mathematics of Quantum Computation, by R. K. Brylinsky and G. Chen CRC, (2002)*
5. *Quantum Computing: A Gentle Introduction, by E. G. Rieffel and W. H. Polak, MIT, (2014)*

Phys 5812	**PHYSICS OF SURFACES AND INTERFACES**	**(CR3)**
Preq.	**Phys 4404**	

Objectives

Surfaces and interfaces play an important role in defining the material's properties in thin film form. The objective of this course is to understand the phenomenon, thermodynamics and physics of fundamental processes occurring at surfaces and interfaces.

Syllabus

Introduction to surfaces and interfaces, surface structure, thermodynamics of surfaces, importance of surfaces and interfaces in materials performance, role of interface in ultrathin materials, processes occurring at the surfaces, surface contamination, surface cleanliness, chemical bonding, interaction of electrons with surfaces, secondary electron emission, energy distribution of secondary electrons, electron scattering, characteristic energy losses in solids, ionization losses, secondary electron yield, secondary emission coefficient, back scattering coefficient, angular variation of yield, high yield secondary emitters, low yield materials, surface effects (contamination, roughness) on yield, application of secondary electron yield, Auger Electron Emission, emission mechanism of Auger electron, Auger electron data acquisition and analysis, chemical shifts in Auger spectra, contamination effects on Auger emission, application of Auger electron spectroscopy. X-ray photoelectron spectroscopy: Basic principles and theory, Photo-ionization cross-section, line-shapes and fine structure, chemical shifts inelastic scattering and sampling depth, instrumentation, X-ray sources, electron energy analyzers, data recording and processing, applications of XPS.

Recommended Books

1. *Solid Surfaces, Interfaces and Thin Films by Hans Luth, Springer (2015).*
2. *Physics of Surfaces and Interfaces by H. Ibach, Springer (2006).*
3. *Surfaces, Interfaces and Colloids: Principles and Application by Drew Myers, 2nd Ed. (1999).*
4. *Methods of Surface Analysis, edited by J. M. Walls, Cambridge, (1988).*