SYLLABUS

FOR

M. Sc. COURSE IN PHYSICS

2020

(CBCS SYSTEM)

DEPARTMENT OF PHYSICS
DIAMOND HARBOUR WOMEN'S UNIVERSITY

Two Year, 4 Semester PG Course in Physics
Grand Total Marks - 1050

(First Year) First Semester

Paper	Subject	Marks in Semester Exam.	Marks in Midterm Evaluation /Sessional	Total Class hours
PHY/CC/TH/101	**Mathematical Methods**	50		75
PHY/CC/TH/102	**Classical Mechanics**	50		75
PHY/CC/TH/103	**Quantum Mechanics-I**	50		75
PHY/CC/PR/104	**Numerical Methods & Computer Applications in Physics**	50		75
PHY/CC/PR/105	**Lab General-I**	50		150
Total		**250**		**450**

(First Year) Second Semester

Paper	Subject	Marks in Semester Exam.	Marks in Midterm Evaluation /Sessional	Total Class hours
PHY/CC/TH/201	**Quantum Mechanics-II**	50		75
PHY/CC/TH/202	**Statistical Mechanics**	50		75
PHY/CC/TH/203	**General Electronics**	50		75
PHY/CC/TH/204	**Electrodynamics**	50		75
PHY/CC/PR/205	**Lab General -II**	50		150
Total		**250**		**450**

(Second Year) Third Semester

Paper	Subject	Marks in Semester Exam.	Marks in Midterm Evaluation /Sessional	Total Class hours
PHY/CC/TH/301	**Condensed Matter Physics**	50		75
PHY/CC/TH/302	**Nuclear & Particle Physics**	50		75
PHY/CC/TH/303	**Atomic & Molecular Physics**	50		75
PHY/CC/PR/304	**Lab General – III**	50		150
Open Elective Paper (CBC, for other discipline)				
PHY/OE/TH/305	Theory (OE)	50		75
PHY/OE/TH/306	Theory (OE)	50		75
Total		**300**		**525**

(Second Year) Fourth Semester:

Paper	Subject	Marks in Semester Exam.	Marks in Midterm Evaluation /Sessional	Total Class hours
PHY/DCA/TH/401A	**Advanced Electronics**	50		75
PHY/DCA/TH/401B	**Advanced Condensed Mather Physics**			
PHY/DCA/TH/401C	**Advanced Atomic, Molecular and Laser Physics**			
PHY/DCA/TH/401D	**Advanced X-ray and Crystallography**			
PHY/DCE/TH/402A	**Astrophysics**	50		75
PHY/DCE/TH/402B	**Non-linear Dynamics**			
PHY/DCE/TH/402C	**High energy particle Physics**			
PHY/DCE/TH/403A	**Nuclear Physics**	50		75
PHY/DCE/TH/403B	**Symmetries and Non-linear waves**			
PHY/DCE/TH/403C	**Quantum field theory**			
PHY/DCE/TH/403D	**Low dimensional structures and**			

	quantum well devices			
PHY/DCPD/404	**Project Dissertation**	50		75
PHY/DCAPR/405	**Advanced Lab**	50		150
Total		**250**		**450**

M. Sc. Course in Physics
P.G. I - First Semester
Paper: PHY/CC/TH/101 (Mathematical Methods)

1**. Vector space and matrices**

Vector space: Axiomatic definition, linear independence, bases, Gram-Schmidt orthogonalization. Matrices: Introduction as representation of linear transformations; Eigenvalues and eigenvectors; Commuting matrices with degenerate eigenvalues; Orthonormality of eigenvectors.

2. Complex analysis

Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable: limit and continuity; Differentiation, Cauchy-Riemann equations and their applications; Analytic and harmonic function; Classification of singularities, Branch point and branch cut; Complex integrals, Cauchy's theorem and its converse, Cauchy's Integral Formula; Taylor and Laurent expansion; Residue theorem and evaluation of some typical real integrals using this theorem.

3. Inhomogeneous differential equations

Green's functions and its applications.

4. Theory of second order linear homogeneous differential equations

Singular points — regular and irregular singular points; Frobenius method; Fuch's theorem; Linear independence of solutions — Wronskian, second solution. Sturm-Liouville theory; Hermitian operators; Completeness.

5. Special functions

Basic properties (recurrence and orthogonality relations, series expansion) of Bessel, Legendre, Hermite and Laguerre functions.

6. Integral transforms

Fourier and Laplace transforms and their inverse transforms; Transform of derivative and integral of a function; Solution of differential equations using integral transforms.

Total Class Hours = 75

Books:

1. J. Matthews and R. Walker, Mathematical Methods for Physics.
2. G. B. Arfken and H. J. Weber, Mathematical Methods for Physics.
3. R. Courant and D. Hilbert, Mathematical Methods for Physics, Vols I and II.
4. P.K. Chattopadhyay, Mathematical Physics.

M.Sc. Course in Physics
P.G. I - First Semester
Paper: PHY/CC/TH/102 (Classical Mechanics)

1. Lagrangian dynamics

Some specific applications of Lagrange's equation; small oscillations, normal modes and frequencies.

2. Hamilton's principle

Calculus of variations; Hamilton's principle; Lagrange's equation from Hamilton's principle; Principle of least action. Legendre transformation and Hamilton's equations of motion.

3. Canonical transformations

Generating functions and examples of canonical transformations; Poisson brackets, Infinitesimal canonical transformation Invariance under canonical transformation.

4. Hamilton-Jacobi theory

The Hamilton Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables.

5. Rigid bodies

Independent coordinates; orthogonal transformations and rotations (finite and infinitesimal); Euler's theorem, Euler angles; Inertia tensor and principal axis system; Euler's equations; Heavy symmetrical top with precession and nutation.

6. Special theory of relativity

Lorentz transformations; 4-vectors, Tensors, Transformation properties, Metric tensor, Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; 4-dimensional velocity and acceleration, 4-momentum and 4-force; Covariant equations of motion; Relativistic kinematics (decay and elastic scattering); Lagrangian and Hamiltonian of a relativistic particle.

Total Class Hours = 75

Books:

1. H. Goldstein, C. Poole and J. Safko, Classical Mechanics.
2. N.C. Rana and P.S. Joag, Classical Mechanics.
3. A.K. Raychaudhuri, Classical Mechanics.
4. L.D. Landau and E.M. Lifschitz, Course on Theoretical Physics Vol. 1: Mechanics.

M.Sc. Course in Physics
P.G. I - First Semester
Paper: PHY/CC/TH/103 (Quantum Mechanics I)

1. Recapitulation of Basic Concepts

Wave packet: Gaussian wave packet; Fourier transform; Spreading of a wave packet. Coordinate and Momentum representations; x and p in these representations. Eigenvalues and eigenfunctions: Momentum and parity operators; Commutativity and simultaneous eigenfunctions; Complete set of eigenfunctions; expansion of wave function in terms of a complete set. One-dimensional problems: Potential well and potential barrier. Reflection and transmission coefficients.

2. Operator method in Quantum Mechanics

Formulation of Quantum Mechanics in vector space language. Uncertainty principle for two arbitrary operators, Linear harmonic oscillator by ladder operator formalism.

3. Angular momentum

Angular momentum algebra; Raising and lowering operators; Matrix representation for $j = 1/2$, $j = 1$; Spin; Addition of two angular momenta — Clebsch-Gordan coefficients.

4. Three-dimensional problems

Three dimensional problems in Cartesian and spherical polar coordinates, Hydrogen atom.

5. Quantum theory of measurement and time evolution

Double Stern-Gerlach experiment for spin- 1/2 system; Schrodinger, Heisenberg and Interaction pictures.

6. Approximation Methods

Time independent perturbation theory: First and second order corrections to the energy eigenvalues, First order correction to the eigenvector; Degenerate perturbation theory; Application to one-electron system – Relativistic mass correction, Spin-orbit coupling (L-S and j-j), Zeeman effect and Stark effect. Variational method: He atom as example; First order Perturbation; Exchange degeneracy, Ritz principle for excited states for Helium atom.WKB approximation.

Total Class Hours = 75

Books:

1. D.J. Griffiths, Introduction to Quantum Mechanics.
2. J.J. Sakurai, Modern Quantum Mechanics.
3. L.I Schiff, Quantum Mechanics.
4. R. Shankar, Principles of Quantum Mechanics.

M.Sc. Course in Physics
P.G. I - First Semester
Paper: PHY/CC/PR/104 (Numerical methods & Computer applications in Physics)

1. Basics of Computer Programming
Writing Computer programs in Fortran or any other scientific language.

2. Plotting
Plotting of functions and data.

3. Finding Roots
Numerical methods for finding roots of equation by: (i) Bisection and (ii) Newton-Raphson

4. Numerical Integration
Numerical Integration by (i) Trapezoidal rule and (ii) Simpson's one-third rule

5. Generation of random numbers
Generation of random numbers and its application towards the bin-packing problem

6. Least square fitting
Least square fitting techniques and its application towards laboratory data set

7. Solving differential equations
Solving first order differential equations by Runge-Kutta fourth order method and its applications towards various physical problems.

8. Linear regression, Interpolation (
Newton's forward and backward interpolation methods

9. **Introduction to LaTeX**
Text formatting and layout, mathematical formatting, Interfacing with LaTeX for symbols and equations, single and multiple graphs insertion, Reference, citations and bibliography, introduction to style files, RevTeX, presentation techniques and application towards dissertation/Project

Total Class Hours = 75

References:

1.Numerical Recipes in Fortran 90 - V. Rajaraman
2. Numerical analysis and computer programming – S.A. Mollah
3. Numerical Recipes in Fortran 90: Vol.2- W.H. Press, S.A. Teukolsky, W.T. Vetterling
4. Numerical Methods in Fortran - J.M. McCulloch and M.G. Salvadori
4. Numerical Methods & Computer Programming –Gottfreit
5. LaTeX – Online tutorials.

M.Sc. Course in Physics
P.G. I - Second Semester
Paper: PHY/CC/TH/201 (Quantum Mechanics II)

1. Time-dependent Perturbation Theory

Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations-Fermi's Golden rule; Sudden and adiabatic approximations. Two level systems, Rabi oscillation.

2. Scattering theory

Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Born approximation. Partial wave analysis and phase shifts; Ramsauer-Townsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering — Green's function in scattering theory; Lippman-Schwinger equation.

3. Identical Particles

Meaning of identity and consequences; Symmetric and antisymmetric wavefunctions; Slater determinant; Symmetric and antisymmetric spin wavefunctions of two identical particles; Collisions of identical particles.

4. Symmetries in quantum mechanics

Conservation laws and degeneracy associated with symmetries; Continuous symmetries — space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for $j = 1/2$ and $j = 1$; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries — parity and time reversal.

5. Relativistic Quantum Mechanics

Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of γ matrices; Charge conjugation; Normalization and completeness of spinors.

Total Class Hours = 75

Books:

1. D.J. Griffiths, Introduction to Quantum Mechanics.
2. J.J. Sakurai, Modern Quantum Mechanics.
3. L.I Schiff, Quantum Mechanics.
4. R. Shankar, Principles of Quantum Mechanics.

M.Sc. Course in Physics
P.G. I - Second Semester
Paper: PHY/CC/TH/202 (Statistical Mechanics)

1. **Review of introductory ideas**
Specification of micro and macro states of a system, Phase space, Counting of number of microstates in phase space.

2. **Statistical ensemble**
Postulate of equal a priori probability, Liouville's theorem, Ergodic hypothesis.

3. **Micro canonical ensemble**
Thermal interaction between systems in equilibrium, Temperature, Heat reservoirs, Sharpness of probability distribution, Applications.

4. **Canonical ensemble**
Equilibrium between a system and a heat reservoir, Distribution function, Partition function, Calculation of thermodynamic quantities, Gibb's paradox.

5. **Grand canonical ensemble**
Equilibrium between a system and a heat reservoir, Distribution function, Partition function, Calculation of thermodynamic quantities.

6. **Quantum statistical mechanics**
Density matrix, Density matrices for different ensembles and their applications, Bose-Einstein and Fermi-Dirac distributions.

7. **Ideal Bose system**
Thermodynamic behaviour of an ideal Bose gas, Bose-Einstein condensation, Liquid helium.

8. **Ideal Fermi gas**
A degenerate electron gas, Thermodynamic behaviour of an ideal Fermi gas, Applications in white dwarfs.

9. **Phase transitions and critical phenomena**
Qualitative description and classification of phase transitions, Ising model, Critical exponents, Order parameters.

10. **Chemical reaction**
Condition for chemical equilibrium, Mass action law, Ionization equilibrium, Saha ionization.

Total Class Hours = 75

References:

1. Statistical Mechanics - R. K. Pathria
2. Statistical Mechanics - K. Huang
3. Fundamentals of statistical and thermal physics – Reif
4. Statistical Physics (III) - Landau and Lifshitz
5. Statistical Mechanics and Properties of matter – E.S.R. Gopal

M.Sc. Course in Physics
P.G. I - Second Semester
Paper: PHY/CC/TH/203 (General Electronics)

1. Electronic Devices

Brief review of p-n junction, p-i-n diode, p-n-p-n structures. Shockley diode, Thyristor, Diac, Triac, UJT - Principle of operation and uses in simple circuits.

2. Electronic Circuits

Network analysis using Laplace and Fourier Transforms. Concept of impedance function, poles and zeros, time domain behavior from pole zero plot. Concept of transfer function.

3. BJT, FET and MOSFET

Revision of pnp and npn transitions, Characteristics curves in CB,CE and CC modes, Two port analysis of a transistor, h-parameters, load line concept, emitter follower, biasing methods, stability factors.

Classification of various types of FETs, construction of junction FET, drain characteristics, biasing, operating region, pinch-off voltage. MOSFET: construction of enhancement and depletion type, principle of operation and characteristics.

4. **Amplifiers**

Analysis of large signal amplifier, distortion in amplifiers, Tuned and Wideband amplifiers, Feedback amplifiers.

5: Modulation

Review of Amplitude and Frequency modulation. Power relation, detection, PLL, AVC, Principle of operation of Super heat receiver.

6. OP-AMP

Brief review of basic OPAMP applications. Active filters, Non-linear circuits, Series regulation of power supply using OPAMP, Switched mode Power Supply.

7: Digitals

Brief review of logic gates, Multivibrators, Flip flops, Counters: ripple, synchronous, ring, monolithic decade. Three stage register. Memories: ROM, EPROM, RAM, TTL Memory, Hexadecimal address, A/D and D/A converter.

Total Class Hours = 75

Books:

1. Solid State Electronic Devices – B.G. Streetman and S.K.Banerjee
2. Fundamentals of Solid State Electronics – C.T.Sah
3. Network and Synthesis – D. Roychoudhury
4. Circuit Theory : Analysis and Synthesis – A. Chakraborty
5. Op-Amp and Linear Integrated Circuits – R. Gayakawad
6. Digital Computer Electronics – A.P.Malvino
7. Integrated Electronics – Millman and Halkais

M.Sc. Course in Physics
P.G. I - Second Semester
Paper: PHY/CC/TH/204 (Electrodynamics)

1. Electrostatics and Magnetostatics

Boundary-value problems in Electrostatics. Neumann and Dirichlet problems. Formal solutions using Green's function, Scalar and vector potentials, Multipole expansion of (i) scalar potential and energy due to a static charge distribution, (ii) vector potential due to a stationary current distribution. Electrostatic and magnetostatic energy, Poynting’s theorem.

2. Maxwell Equations

Maxwell Equations, Macroscopic Electromagnetism, Electrodynamics. Conservation laws, Poynting's theorem.

3. Electromagnetic waves

Plane Electromagnetic Waves and Wave Propagation. Effects of earth’s magnetic field on the Propagation through ionosphere. Polarization; Reflection, Transmission, Total internal reflection, Waves in conducting medium, TE-, TM-, TEM waves, Waveguides, Matching and attenuation, Excitation of modes, Resonant Cavity.

4. Moving charges

Scalar and Vector Potential. Coulomb and Lorentz gauge. Retarded potentials. The Liennard-Wiechart potential. Time dependent Green's function.

5. Radiation

Radiation. Electric and magnetic dipole radiation, radiation from moving charges. Linear antenna. Antenna Arrays, Cerenkov radiation.

6. Lagrangian formulation Relativistic electrodynamics

Idea of a classical field as a generalized coordinate. Euler-Lagrange equation for the field from the Lagrangian density. The field momentum and the Hamiltonian density. Poisson brackets for the fields. Equation of motion in an electromagnetic field; Electromagnetic field tensor, covariance of Maxwells equations; Maxwell’s equations as equations of motion; Lorentz transformation law for the electro-magnetic fields and the fields due to a point charge in uniform motion; Field invariants; Covariance of Lorentz force equation and the equation of motion of a charged particle in an electromagnetic field; The generalized momentum; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field.

Total Class Hours = 75

Books:

1. J.D. Jackson, Classical Electrodynamics.
2. W.K.H. Panofsky and M. Phillips, Classical Electromagnetism.
3. D.J. Griffiths, Introduction to Electrodynamics.
4. L.D. Landau & E. M. Lifschitz, Course on Theoretical Physics Vol.2: Classical Theo of Fields

M.Sc. Course in Physics
P.G. II - Third Semester
Paper: PHY/CC/TH/301 (Condensed Matter Physics)

1) **Crystallography**
Review of preliminary ideas, Bravais lattice and primitive vectors, primitive unit cell, Wigner Seitz cell, Reciprocal lattice, Brillouin Zone, Bragg and Laue formulation of X-ray diffraction, geometrical interpretation of Bragg's law, atomic and crystal structure factor, simple crystal structure – Diamond, Zinc blende, NaCl, CsCl etc., structure factor calculation.

2) **Lattice dynamics**
Phonon and lattice vibrations, harmonic approximation, adiabatic approximation, vibrations of linear monatomic and diatomic lattices, normal modes and phonon lattice specific heat capacity, Debye model of specific heat capacity.

3) **Band theory of solids**
Bloch equation, empty band, nearly free electron theory, band gap, number of states in a band, tight binding approximation, effective mass of an electron in a band, concept of holes, classification of metal, semiconductor and insulator, topology of Fermi surface, cyclotron resonance de Haas-Van Alphen effect.

4) **Magnetic properties of solids**
Quantum theory of paramagnetism, spin paramagnetism, Pauli theory, Heisenberg's theory of ferromagnetism, antiferromagnetism.

5) **Magnetic resonances**
Nuclear magnetic resonance, Bloch equation, longitudinal and transverse relaxation time, hyperfine field, electron spin resonance.

6) **Imperfections in solids**
Frenkel and Schottky defects, defects in crystal growth, colour centres and photoconductivity, luminescence , alloys – order- disorder phenomena, Brag – Williams theory.

7) **Superconductivity**
Phenomenological description of superconductivity, critical temperature, Meissner effect, magnetic properties, critical field, London equation, microscopic theory, qualitative features.

Total Class Hours = 75

Books:

1) Introduction to Solid State Physics, Charles Kittel, John Wiley & Sons.
2) Solid State Physics, Neil W.Ashcroft and N.David Mermin, Harcourt Asia PTF Ltd.
3) Books on Advanced Condensed matter Physics

M.Sc. Course in Physics
P.G. II – Third Semester
Paper: PHY/CC/TH/302 (Nuclear and Particle Physics)

1. General properties of Nuclei:
Nuclear properties, size, mass, spin, binding energy, electric and quadrupole moments, empirical mass formula, stable nuclei, classification, isotopes, isotones and isobar, mass parabola for isobars.

2. Nuclear Forces:
Nature of nuclear forces, Yukawa hypothesis, general properties of deuteron , ground state with square well potential, relation between range and depth, experimental evidence of tensor force, parity, admixture of D and S state. Low energy n-p scattering, Fermi Scattering length.

3. Nuclear Decay:
Alpha decay: General features, Gamow theory of alpha decay.

Beta decay: General features, Fermi theory of beta decay, selection rules, Kurie plot, parity non conservation, Wu's experiment, origin of continuous beta spectrum, neutrino properties and detection.

Gamma decay: Multipolarity of gamma rays, selection rules, gamma ray spectra and nuclear energy level, internal conversion, Mossbauer effect, interaction of gamma rays with matter.

4. Nuclear Models:
Shell model, Fermi gas model, Liquid drop model, collective model.

5. Nuclear Reactions:
Type of nuclear reaction, conservation laws in nuclear reaction, Q value, experimental determination of Q value, reaction induced by alpha particle, proton, neutron and gamma ray.

6.. **Particle Physics:**
Classification of elementary particles, Mesons, Baryons, leptons, basic forces of nature and their characteristics, coupling constants, Feynman diagram of basic interactions, mediators, characteristics of strange particles, internal quantum numbers, baryon numbers, lepton number, hypercharge, isospin quantum number and isospin symmetry in strong interaction, Eightfold way, meson Octet, baryon Octet, baryon decuplet, Quark model for baryon and mesons in Eightfold scheme, Gellman-Nishijima formula, color quantum number and quark confinement (Qualitative feature) , decay of elementary particles, conservation laws, forbidden and allowed decay of particles, qualitative discussion on neutrino oscillation.

Total Class Hours = 75

Books:

1. Nuclear Physics : S.N.Ghoshal
2. Nuclear Physics : R.R. Roy and B.P.Nigam
3. Introduction to Elementary Particles: David Griffiths

M.Sc. Course in Physics
P.G. II – Third Semester
Paper: PHY/CC/TH/303 (Atomic & Molecular Physics)

One electron Atom

1. Recapitulation of one electron atom; Energy eigenvalues and eigenfunctions of hydrogenic atom, parity, expectation values. (1)
2. Fine structure and hyperfine structure of one electron atom. (2)
3. Lamb-Rutherford experiment. Lamb Shift (qualitative) (2)
4. Interaction of hydrogen atom with electromagnetic radiation, absorption, stimulated and spontaneous emissions. Einstein's A and B coefficients. Selection rules. (2)
5. Magnetic & Electric effects **:** Normal and anomalous Zeeman effect, Paschen-Bach effect and Stark effect for one electron atom. (3)

6**. Many electron atoms**

Central field approximation, Slater determinant, electronic configurations – shells, subshells, degeneracies, L-S coupling, j-j coupling, Hund's rule, Lande interval rule, Hartree-Fock self-consistent field approximation. Spectra of alkali atoms.

7. **Molecular structure**

Molecular Hamiltonian, Born-Oppenheimer approximation, electron shells of di-atomic molecules, hydrogen molecular ion by LCAO method, calculation of bond length and dissociation energy, shapes of molecular orbitals, pi and sigma bonds.

8. **Molecular rotation and vibration**

Solution of nuclear equation, molecular rotation: rigid and non-rigid rotator, centrifugal distortion, symmetric top molecules, molecular vibration: harmonic oscillator approximation and harmonicity, Morse potential.

9. **Molecular Spectra**

Electronic, vibrational and rotational transitions in diatomic molecules, vibration-radiation spectra, Frank-Condon principle

10. **Raman Spectra**: pure rotation Raman spectra, vibrational Raman spectra. Polarization and Raman effect.

11. **Lasers** : Population inversion, three level laser, He-Ne laser – principle of operation, tunable lasers, laser induced reactions and isotope separation.

12. **NMR ESR** : Introduction to spin resonance spectroscopy, NMR and ESR

Total Class Hours = 75

Books:

1. Physics of atoms and molecules – B.H.Bransden and C.J.Joachain
2. Fundamentals of Molecular spectroscopy – C.N.Banwell
3. Fundamentals of Molecular spectroscopy – Barrowl
4. Molecular spectra and Molecular structure Vol. I & II - G. Herzberg

Open Elective Paper (CBC, for other discipline)

M.Sc. Course in Physics
P.G. II – Third Semester
Principles of Relativity and Cosmology (PHY/OE/TH/305)

1. Tensor Analysis: Covariant and Contravariant tensors, Metric tensors, Parallel transport and covariant differentiation, Affine connection and its relation to metric tensors, Curvature tensor and its symmetries, Bianchi identity, Weyl tensor and conformal invariance

2. Geodesics: Equation of motion of particles, Galilean transformations, Newtonian relativity, Electromagnetism and Newtonian Relativity, Lorentz transformations, Postulates of special theory of relativity and their consequences, Concept of light cone, causality, past and future cones

3. The principle of equivalence and principle of general covariance, Einstein's field equation – Newtonian gravity as an approximation, the Schwarzschild solution, Radial motion towards center, Energy momentum tensor for a perfect fluid, equation of motion from field equation for dust.

4. Action principle for field equations, Introduction to compact objects, formation of compact objects, Physical properties of white dwarfs. The Chandrasekhar limit comparison with observations: Masses and radii, physical properties and discovery of Neutron stars. Observation of neutron star, Masses and maximum mass limit properties of Schwarzschild black holes.

5. Cosmological principles, Weyl postulates, Robertson-Walker metric (derivation not required), Cosmological parameters, static universe, expanding universe, open and closed universe, cosmological red shift, Hubble's law, Olber's Paradox, Qualitative discussions on: Big bang, early universe (Thermal history and Nucleosynthesis), Cosmic Microwave Background Radiation (CMBR), event horizon, particle horizon and some problems of standard cosmology.

M.Sc. Course in Physics

P.G. II – Third Semester

Elements of Condensed matter and Nano Physics (PHY/OE/TH/306)

Course Objective: This is an introductory solid state physics course. Background in quantum and statistical physics is not mandatory, making this course suitable for students from a wide background of various science disciplines.

1. Crystallography:
   Crystallography and amorphous solids, the crystal lattice, basis vectors, unit cell, Miller indices, inter-planer spacing, simple crystal structures: FCC, BCC, Nacl, CsCl, Diamond and ZnS structure.
2. X-ray diffraction:
   Diffraction by crystals, Lau theory, Interpretation of Lau equations, Bragg's law. Reciprocal lattice, Ewald construction, atomic scattering factor.
3. Lattice Vibration:
   Vibrations of one-dimensional monoatomic and diatomic lattices. Normal modes and phonons, review of Debye's theory of lattice specific heat.
4. Electronic properties of solids:
   Concept of energy band diagram for materials – conductors, semiconductors and insulators, electrical conductivity effect of temperature on conductivity, intrinsic and extrinsic semiconductors, dielectric properties.
5. Magnetic properties of Solids:
   Origin of magnetism, para-magnetism, diamagnetism, antiferromagnetism, ferromagnetism, ferrimagnetism, magnetic hysteresis.
6. Superconductivity:
   Superconductivity, Survey of important experimental results, critical temperature, Meissner effect, Type-I and Type-II superconductors, Thermodynamics of superconducting transition, London equation, Energy gap, basic ideas of BCS theory.
7. Nano-Physics:
   Introduction, 1D nanoscale, 2D nanoscale, 3D nanoscale, Composite, magnetic nano materials, different nanomaterial synthesis technique,
   Application of nanomaterials: visible LED, infrared LED, sensors, photo detectors, photoconductors, photodiodes, phototransistor, solar cells.
8. Experimental Technique:
   Experimental techniques for study of materials using X-ray diffractometer, UV visible spectrometer and Photoluminescence spectrometer.

Lab: General & Advanced

P.G. I - First Semester: PHY/CC/PR/105 (Lab General - I)

1. Hall effect Expt.
2. P-N junction characteristics.
3. R-C coupled amplifier.
4. Band gap by 4-probe method.
5. Characteristics of Op-Amp-I : Voltage comparator, Logarithmic amplifier, Schmitt trigger .
6. Characteristics of Op-Amp-II: Integrator, Differentiator, Digital to analog converter.

P.G. I - Second Semester: PHY/CC/PR/205 (Lab General - II)

1. Measurement of Planck's constant.
2. Characteristics of Solar cell.
3. Ultrasonic interferometer.
4. Measurement of Magneto Resistance of Semiconductor
5. Digital Experiments-I : 4:1 MUX, De-MUX(4 input$\underline{=}$7 seg. display), J-K flip-flop.
6. Digital Experiments-II: Decade counter: Mod-3/5, Counter (up/down), Astable Multivibrator.

P.G. II – Third Semester: PHY/CC/PR/304 (Lab General - III)

1. e/m Experiment.
2. Lattice Dynamics.
3. Transmission Line Characteristics.
4. X-ray diffraction study
5. Nuclear Magnetic Resonance Spectrometer
6. Laser power distribution expt.: Diode laser / He-Ne laser

PG-II – Fourth Semester: PHY/DCAPR/405A (Lab Advanced Electronics)

1. Study of Power Supply (Solid state model: Rectifier, Filter, Regulation)
2. Characteristics of Gunn diode
3. Optical Transducer Trainer Kit: Characteristics of (a) photovoltaic cell, (b) photoconductive cell, (c) photo transistor (d) photo diode
4. Fiber Optics Trainer Kit: To study various characteristics of optical fiber
5. Power Electronics Trainer Kit: To study I-V characteristics of- MOSFET, IGBT, PUT, SCR, DIAC, TRIAC.
6. Characteristics of Tunnel Diode.

PG-II – Fourth Semester: PHY/DCAPR/405B (Lab Adv. Condensed Mather Physics)

1. Dependence of Hall Coefficient on Temperature.
2. Study of Dielectric Constant and Curie Temperature of Ferroelectric material.
3. Measurement of Susceptibility of Paramagnetic solution by Quinck's Tube Method.
4. Four Probe set-up for measuring the Resistivity of very low to high resistive samples at different temperatures.
5. Hysteresis loop tracer: Measurement of Coercivity, Saturation magnetization, Retentivity.
6. Study of Thermo-luminescence of F- centers in crystals.

PG-II – Fourth Semester: PHY/DCAPR/405C (Lab Adv. Atomic, Molecular & Laser Physics)

1. Determination of Rydberg constant: Frank –Hertz expt.
2. Determination of Lande g-factor: Electron Spin Resonance (ESR) Spectrometer.
3. Study of Zeeman Effect.
4. Iodine Spectra Experiment.
5. Laser kit experiment- measurement of power distribution, wavelength, grating element etc.
6. Michelson interferometer Or Fabry-Perot interferometer.

PG-II – Fourth Semester: PHY/DCAPR/405D (Lab Adv. X-ray and Crystallography)

1. Identification of Lattice and Determination of Lattice Constant by X-Ray Diffraction Simulation (SES Instruments)

Simulated 3-dimensional lattices of crystalline solids used for the determination of lattice constant. The crystal lattice is available in the form of slides and laser light replaces x-rays, thus making the experiment simpler, safer and of lower cost.

2. Index the X-ray powder diffraction pattern of a powder, crystal.
3. Identification of crystal phases by using X-ray powder diffraction method.
4. Preparation and characterization of nano-crystalline materials using X-ray diffraction patterns
5. Determination of crystalline size by X-ray powder diffraction.

Discipline Centric Advanced and Elective Paper (Optional Special Paper)

[#]Advanced Subjects: (Paper: PHY/DCA/TH/401A, 401B, 401C, 401D)

2. Advanced Electronics
3. Advanced Condensed Matter Physics
4. Advanced Atomic, Molecular and Laser Physics
5. Advanced X-Ray and Crystallography

***Elective Subjects: (Paper: PHY/DCE/TH/402A, 402B, 402C, 403A, 403B, 403C, 403D)**

1. Astrophysics
2. Non-linear Dynamics
3. High Energy Particle Physics
4. Nuclear Physics
5. Symmetries and Nonlinear waves
6. Quantum field theory
7. Low dimensional Structures and quantum well devices

Advanced Subjects

Advanced Electronics (PHY/TH/401A)

1. **Electronic Materials :** Conductor, semiconductor and insulator, energy bands, effective mass tensor, density of states effective mass, calculation of Fermi level, incomplete ionization of impurity levels at low temperatures, carrier collision with crystalline imperfections, matrix elements, scattering probabilities, randomizing and elastic collisions, relaxation time, dominant relaxation processes in different materials and at different temperatures. Solution of Boltzmann transport equation, relaxation time approximation, low field transport coefficient, Hall effect, magneto resistance, features of carrier transport in strong electric and magnetic fields. Cyclotron resonance. energy levels and density of states in presence of a magnetic field. Landau diamagnetism, de-hass Van alphen effect, transport behavior of excess carriers, continuity equation, Shockley-Haynes experiment, recombination processes, surface recombination, steady state and transient photoconductivity, Shockley Read theory, methods of growth of single crystals and thin film deposition, conductivity characteristics of thin films.

2. **Metal-semiconductor contacts**: Energy band relation, surface states, depletion layer, Schottky effect, current transport processes, thermionic emission theory, diffusion theory, tunneling current, minority carrier injection ratio, characterization of barrier heights, device structures, Ohmic contact

3. FET: Basic characteristic, charge distribution, field dependent mobility, two-region model, saturated velocity model, microwave performance, related field effect devices, current limiter, multichannel FET.

4. Electronic Devices: Device modeling, Ebers-Moll equation, Gummel-Poon model, power transistor, switching transistor, hot-electron transistor.

5. **Tunnel devices** : Tunnel diode, tunneling probability, tunneling current, current-voltage characteristics, Backward diode, MISD tunnel diode, MIS switch diode, MIM Tunnel diode, Tunneling emitter transistor.

6. **IMPATT and transit time diode**: Static and dynamic characteristics, power and efficiency, device performance, BARITT, DOVETT and TRAPATT diodes.

7. **Transferred electron devices**: Bulk negative differential resistivity, modes of operation, Gunn diode, device performance.

8. **Photonic devices**: visible LED, Infrared LED, sensors, photo detectors, photoconductors, photodiodes, phototransistor, solar cell, p-n photovoltaic effect. Optical fiber wave guide, index profile, numerical aperture, pulse dispersion, Multimode fiber with optimum profile, fiber optic communication systems, cables, splices and connectors, losses in optical fibers.

Total Class Hours = 75

Books:

1. Physics of Semiconductor Devices – S.M.Sze
2. Solid State Electronic Devices – B.G. Streetman and S.K.Banerjee
3. Theory of Electrical Transport in Semiconductors – B.R.Nag
4. Optical Electronics – A. Ghatak and K Thyagrajan
5. Optical Electronics – A. Yariv

Advanced Condensed Matter Physics (PHY/DCA/TH//401B)

1. Lattice dynamics:
3-D lattice vibration in the harmonic approximation, cyclic boundary condition, phonon frequency distribution and dispersion relations. Diffraction of X-rays and neutrons by phonons, Debye-Waller factor, equation of state of a solid.

2. Many-electron Theory:
Adiabatic approximation, Self-consistent solution of Hartree and Hartree-Fock equation for electron gas.

3. Band Theory:
Bloch's theorem, equivalent and non-equivalent wave vectors; empty lattice band Fermi surface for nearly free electron model, method of tight binding, OPW, APW and KKR Methods. Symmetrized wave function, effective mass theory.

4. Electronic Properties:
Transport equation, Electronic and thermal conductivity. Transport equation in presence of magnetic field, cyclotron resonance, Landau diamagnetism, de Hass-van Alphen effect

5. Dielectric Properties:
Dielectric polarization, relaxation, Debye equation. Polarization catastrophe – Onsager-Kirkwood theory, Ferroelectricity – phenomenological theory of phase transition, Lyddane Sachs-Teller relation in ferro electronics

6. Optical properties of solids:
Colour of crystals, photoconductivity, luminescence, exciton. Defects in solids –colour centres, other electronic centres, dislocation, diffusion

7. Superconductivity and Superfluidity:
Electrodynamics of superconductors – London's equation and Pippard's (non-local) equation; The BCS theory, Ginzburg – Landau theory; magnetic properties of Type – II superconductors; Josephson effect. Hg-Te superconductors.
Superfluidity – London's argument, Liquid He 3 as a dilute Fermi gas, qualitative features of London Theory.

Total Class Hours = 75

Books:

1. Solid State Physics – Zeeman
2. Solid State Physics – N.W. Aschroft and N.D. Mermin
3. Theoretical Solid State Physics - W. Jones and N.H. March
4. Intermediate Quantum Theory of Crystalline Solids – Alexander O.E. Animalu

Advanced Atomic, Molecular and Laser Physics (PHY/DCA/TH/401C)

1. M**any electron atoms** :
Many electron Hartree-Fock theory, Slater determinant, Koopmann's theorem- evaluation of matrix elements, LS, JJ and intermediate coupling schemes, Thomas-Fermi approximation, Configuration interaction, Doubly and multiply excited states, Autoionization

2. Molecular structure :
Electronic structure of diatomic molecules, Term symbol for diatomic molecules, United and separated atom description, LCAO and VB methods, Application to hydrogen molecule, Bond length and dissociation energy. Classification of molecules, Normal modes of vibration.

3. Molecular Spectra :
Review of rotation (rigid and non-rigid models), and vibration (harmonic and anharmonic oscillator models) spectra, Vibrating rotator model- P, Q and R branches in molecular spectra, Electronic spectra, Band formation and band heads, Progressions and sequences, Intensity of molecular bands, Franck-Condon principle, Condon parabola, Fluorescence and phosphorescence.

4. Scattering theory :
Review of theory of scattering cross section, Basic theory of first Born approximation, Eikonal approximation, Idea of different collisional processes- electron capture, ionization & excitation.

5. Lasers:
Principle of Laser, Rate equation, Three and four level lasers, Semiconductor laser, Tunable and pulsed lasers, Nd-Yag laser, Atom laser, Applications of laser in physics, chemistry and biology.

6. Modern spectroscopic techniques:
Basic idea and principles of modern spectroscopic techniques- Electron microscopy, Scanning electron microscopy, Tunneling electron microscopy.

Total Class Hours = 75

Books:

1. Physics of atoms and molecules – B.H.Bransden and C.J.Joachain
2. Introduction to Atomic Spectra - E. White (Tata McGraw Hill)
3. Theory of Atomic Spectra - Condon and Shortley (Cambridge)
4. Fundamentals of Molecular spectroscopy - Barrow
5. Fundamentals of Molecular spectroscopy – C. N. Banwell and E. M. McCah.
6. Quantum Chemistry - I. N. Levine (PHI)
7. Molecular spectra and Molecular structure Vol. I, II & III - G. Herzberg (Van Nostrand)
8. Laser Physics – AK. Ghatak (Tata McGraw Hill)
9. Optical Electronics - A. Ghatak and K. Thyagarajan (Cambridge)

Advanced X-ray and Crystallography (PHY/DCA/TH/401D)

Objective of this Course

The objective of this course is to present the basic concepts needed to understand the crystal structure of materials. Fundamental concepts including lattices, symmetries, point groups, and space groups will be discussed and the relationship between crystal symmetries and physical properties will be addressed. The theory of X-ray diffraction by crystalline matter along with the experimental x-ray methods used to determine the crystal structure of materials will be covered. Application of X-ray diffraction to different material and electron diffraction will be briefly discussed.

Goal of the Course

At the end of this course students should be able to, define concepts such as lattice, point and space groups, be familiar with Bragg's Law and explain it's relation to crystal structure, identify and describe different diffraction methods, interpret and assign X-ray and electron diffraction patterns

Course Contents

Fundamentals of X-rays

Production and properties of X-rays, X-ray emission and Absorption spectra, Moseley's law, Diffraction of X-rays, Laue equation, Reflection from crystal planes, Bragg's law, Bragg spectrometer.

Crystal Structure and Symmetries/ Geometrical Crystallography

Symmetry in crystals, Zone and forms, Crystal lattice, symmetry elements, point group, stereographic projections, matrix representation, space lattice, crystal system, space groups, diagrammatic representation

Crystal Diffractions

Diffraction by a small single crystal, Laue equations, atomic scattering factor, crystal structure factor, Reciprocal lattice, integrated intensity and reflecting power, diffraction by polycrystalline aggregate, Scherrer equation, dynamical theory, Darwin's theory, Ewald's dynamical theory

Determination of Crystal Structure

Geometrical and physical factors affecting intensity of X-ray diffractions, Fourier representation of electron density, phase problem in crystallography, Patterson function, Harker section, heavy atom method for structure solution, isomorphous replacement and anomalous scattering, direct methods, Harker-Kasper inequality, Refinement,

Application of X-ray diffraction and related topics

Phase identification, Quantitative phase analysis, Accurate lattice parameter determination, Crystallite size measurement, Structure of poly crystalline material, Rietveld method,

Total Class Hours = 75

References:

1. Phillips, F.C (1971): Introduction to Crystallography, Longman Group Publ.
2. Crystals and Crystal structures, R.J.D. Tilley, John Wiley and Sons, 2006
3. Introduction to Solids Leonid V. Azaroff
4. Crystallography applied to Solid State Physics, A.R. Verma and O.N. Srivastava
5. An introduction to X-ray crystallography by Michael Woolfson
6. Crystal structure determination by Werner Massa
7. X-ray Structure Determination: A Practical Guide by George H. Stout
8. Structure determination by X-ray crystallography by M. F. C. Ladd
9. Fundamentals of Powder Diffraction and Structural Characterization of Materials by Peter Zavalij and Vitalij K. Pecharsky
10. X-ray Crystallography by William Clegg

Elective Subjects

Astrophysics (PHY/DCE/TH/402A)

1. **Basic concepts of Astronomy**
Celestial sphere, Celestial coordinate system, astronomical events, different measurement scales in astronomy.

2. **Radiative Transfer**
LTE state, Radiative transfer equation, optical depth, Limb darkening, opacity.

3. **Stellar structure and evolution**
Star formation, H-R diagram, virial theorem, equation for stellar structure and evolution, polytropic model, Lane-Emden equation with analytic solutions, degeneracy pressure, Chandrasekhar limit, star collapse, time scale for a free falling object, white dwarfs, neutron stars, pulsars, solar neutrino problem, virial theorem for dynamics, Collisional relaxation, Incompatibility of thermodynamic equilibrium and self-gravity, Boltzmann equation, Jeans equation, mean molecular weight in astrophysics.

4. **Cosmology**
Introduction to Cosmology, Hubble's law, Cosmological principle, homogeneous and isotropic world models, co-moving coordinate, Friedmann model, Radiation and matter dominated universe, distance scale, age of the universe, density parameter, cosmological parameter, de-acceleration parameter, cosmic microwave background radiation (CMBR), horizon problem, flatness problem, dynamics of galaxies, dark matter, red shift surveys and distance measurements, Space-time fabric of the Universe, Friedman-Robertson-Walker metric, Gravitational redshift, Schwarzschild metric, Singularities and the concept of a horizon.

5. **Plasma astrophysics**
Concept of plasma, Debye screening, Fluid model, plasma oscillations, plasma wave, Magneto hydrodynamics(MHD) equations, Magnetic diffusion, viscosity and pressure, magneto-hydrodynamic flow, pinch effect and its dynamic model, instabilities, Qualitative discussion on sausage and kink instability, plasma sheath, wake fields.

Total Class Hours = 75

References:

1. Text book of astronomy and astrophysics with elements of cosmology- V. B. Bhatia, Narosa
2. Astrophysics- stars and galaxies- K.D. Abhyankar, Universities press.
3. An introduction to the study of stellar structure- S. Chandrasekhar, Dover.
4. Principles of Physical Cosmology- P.J.E. Peebles, Princeton University Press.
5. Cosmological Physics- John A. Peacock, Cambridge University Press.
6. Cosmology- Steven Weinberg, Oxford University Press.
7. Modern Cosmology- Scott Dodelson, Academic Press.
8. Introduction to Cosmology- J.V. Narlikar, Cambridge university press.
9. Theoretical Cosmology- A.K. Raychaudhuri, Oxford press.

Nonlinear Dynamics (PHY/DCE/TH/402B)

1. Introduction:

One-dimensional systems: Flows on the line. Fixed points and stability, graphical analysis, linear stability analysis. Existence and uniqueness of solutions. Impossibility of oscillations in one dimension. Flows on the Circle : Possibility of oscillations, Superconducting Josephson Junction, Equivalent circuit and damped, driven pendulum analogue. Bifurcations in one dimensional systems and their classifications. Imperfect bifurcations and catastrophes.

2. Two-Dimensional Flows:

(a) Linear Systems and classification. Nonlinear systems: linearization and Jacobian matrix, analysis in polar coordinates. Conservative systems, reversible systems. (b) Lyapunov function, gradient systems, Dulac criterion, limit cycle, Poincare-Bendixson theorem, Lienard systems. Analysis of two widely separated time-scales, Poincare-Lindstedt perturbation method.

3. Chaos I:

One dimensional map : Stability, Liapunov exponent, chaos; Logistic map : period-doubling route to chaos, estimation of α and δ from renormalization arguments.

4. Chaos II :

Fractals : examples and dimension; Rayleigh-Benard convection: basic equations, Boussinesq approximation; Lorenz map : Stability of fixed points and appearance of strange attractors; Baker’s map; Henon map.

Total Class Hours = 75

Books:

1. S. H. Strogatz, Nonlinear Dynamics and Chaos
2. R.L. Devaney, An Introduction to Chaotic Dynamical Systems.
3. D.W. Jordan and P. Smith, Nonlinear Ordinary Differential Equations.
4. G.L. Baker and J.P. Gollub, Chaotic Dynamics - An Introduction.

High Energy Particle Physics (PHY/DCE/TH/402C)

1. **Interaction of Elementary Particles:** Type of interaction between the elementary particles, Feynman diagram, mediators, hadrons, basic building blocks of nature quark and leptons, resonance particles, internal quantum numbers and Gellman Nishijima formula. The Eightfold way, Quark model of mesons and baryons. Decay of elementary particles, symmetries and conservation laws, charge conjugation, CP violation in weak interaction, CPT theorem, properties of neutrinos, parity, quark-lepton symmetry, Neutrino oscillations.

2. **Hadron spectroscopy:** Hadron spectroscopy, Multiplets and quarks. Quark flavors, SU(2) representation-fundamental representation of SU(2) doublet, iso spin, conjugate and regular representation of SU(2). Representation of SU(3), Young Tableaux.

3. **Invariant Lagrangian:** Invariant Lagrangian, U(1) symmetry, Globally and locally invariant lagrangians, Gauge fields, Degeneracy of vacuum states and spontaneous breakdown of symmetry, Standard model of electroweak interaction-construction of lagrangian SU(2)* U(1) group, extension of standard model to include quarks (qualitative).

4. **DIS:** Dynamical structure of hadrons, deep inelastic scattering, structure function, Bijorken scaling, exact scaling and scaling violation.

5. **QCD :** Theory of strong interaction, introduction of colour degree of freedom, quantum chromo dynamics (QCD), gluons, running coupling constant and asymptotic freedom.

Total Class Hours = 75

Books:

1. Introduction to Elementary Particles: David Griffiths
2. An introduction to Quarks and Partons: F.E. Close.
3. Introduction to Gauge Field Theories: M Chaichian and N.F. Nelipa.

Nuclear Physics (PHY/DCE/TH/403A)

1. **Nuclear Forces**

Nuclear Forces, Phenomenological two nucleon potential, Symmetry and nuclear forces, general form of two nucleon potential. Excited state of deuteron, magnetic moment and quadrupole moment of deuteron, deuteron with non central potential and deuteron D-state.

2. Nuclear structure

Vibrational model, Breathing mode, quadrupole and octupole vibrations, Giant resonance, Gamow-Teller resonance, Nilsson unified model for deformed potential. Collective model-quantum mechanical treatment, Nuclear shell model-effective Hamiltonian.

5. **Nuclear reactions**

Coulomb excitation, compound nucleus formation, Direct reaction, Statistical theory of multi step compound reaction.

3. **Two nucleon interaction**

Phenomenology of two nucleon interaction, Scattering of two nucleon system, p-p scattering at high energy, phase shift analysis, S-matrix approach, Nuclear form factor.

4. **Interaction of nuclear radiation**

Interaction of nuclear radiation with matter, energy loss of heavy charged particle passing through medium, ionization, photo electric effect, Compton scattering, pair production process, Bremstrahlung process.

Total Class Hours = 75
Books:

1. Nuclear Physics: Enrico Fermi.
2. Introductory Nuclear Physics: Samuel S.M. Wong.
3. Nuclear Physics : S.N.Ghoshal
4. Nuclear Physics : R.R. Roy and B.P.Nigam

Symmetries and Nonlinear waves (PHY/DCE/TH/403B)

Course objective:

Most well-known techniques for obtaining exact solutions of ordinary and partial differential equations rely on the existence of an underlying symmetry of the systems in question. The fundamental ideas behind symmetry methods are essentially simple but are so far reaching that they are still the basis of much research and form an essential asset for the student.

Nonlinear waves are ubiquitous in the natural world and an exposure to some of the more well known equations such as the KdV and NLSE constitute a vital ingredient of a students' post-graduate training.

The combined course will require a combination of different mathematical techniques and skill and may also be suitable for post-graduate students of mathematics (applied) and may therefore be construed as an inter-disciplinary course in future.

Course contents:

1. *Introduction to symmetries*:
   Symmetries of planar objects and simple ordinary differential equations (ODEs), the symmetry condition for first-order ODEs, Lie symmetries for first-order ODEs, canonical coordinates, solving ODEs via Lie symmetries.

2. *The linearized symmetry condition:*
   The determining equations for Lie point symmetries, reduction of order using canonical coordinates, infinitesimal generator, Variational symmetries, Invariant solutions Noether's theorem.

3. *Lie symmetries:*
   Differential invariant and reduction of order for ODEs, Lie algebra of point symmetry generators, solution of ODEs using a solvable Lie algebra.

4. *Review of linear wave theory*
   Linear wave equation, the method of Fourier transforms for solving linear equations, dispersion relation, group velocity, elementary travelling wave solutions and scaling solutions of partial differential equations.

5. *Nonlinear Partial differential equations:*
   Historical remarks and the discovery of the soliton, solitary waves , derivation of the Korteweg-de-Vries (KdV) equation, travelling wave solutions and dispersion relations

for the KdV, soliton solution (one and two-soliton solution only), derivation of the Nonlinear Schrodinger equation (NLSE), the Sine-Gordon equation, Lax pair for KdV and NLS equation and their conserved quantities.

6. *Physical applications of Nonlinear PDE’s:*
   KdV equation in plasma physics, electrical transmission lines and water waves;
   NLSE in nonlinear fibre optics.

Leaning Outcomes:

The course is intended to familiarize students with basic symmetry methods for nonlinear ODEs and to provide an introduction to various well known nonlinear PDEs including exposure to their applications in various physical situations.

References:

(1) P.E Hydon-Symmetry methods for Differential equations, Cambridge Univ. Press

(2) Symmetry and Integrations methods for Differential Equations, GW Bluman and S C Anco, Springer.

(3) Solitons : an introduction: P G Drazin and R S Johnson, Cambridge Univ. Press 1989

Quantum Field Theory (PHY/DCE/TH/403C)

1. Lorentz Group
Continuous and discrete transformations, Group structure, Proper and improper Lorentz Transformations, SL(2,C) representations, Poincare group.

2. Canonical quantization of free fields
Real and complex scalar fields, Dirac field, electromagnetic field, Bilinear covariant, Projection operators, Charge conjugation and Parity on scalar, Dirac and electromagnetic fields.

3. Interacting fields
Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.

4. QED
Feynman rules, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton, $e + e - \rightarrow \mu + \mu -$. Decay and scattering kinematics. Mandelstam variables and use of crossing symmetry.

5. Higher order corrections
One-loop diagrams. Basic idea of regularization and renormalization. Degree of divergence. Calculation of self-energy of scalar in φ 4 theory using cut-off or dimensional regularization.

6. Gauge theories
Gauge invariance in QED, non-abelian gauge theories, QCD (introduction), Asymptotic freedom, Spontaneous symmetry breaking, Higgs mechanism.

Total Class Hours = 75
Books:

1. M.E. Preskin and D.V. Schreder, An Introduction to Quantum Field Theory.
2. Ashok Das, Lectures on Quantum Field Theory.
3. A. Lahiri and P. Pal, A First Book in Quantum Field Theory.

Low Dimensional Structures and Quantum Well Devices (PHY/DCE/TH/403D)

1. **Heterostructure Growth** Molecular Beam Epitaxy, Metal Organic Vapor Deposition, Chemical Beam Epitaxy.

2**. Low-dimensional structures:** 2D, 1D and 0D structures, Nano structures, Graphene, density of states function, equilibrium concentration of carriers.

3. **Band Offset:** Types of heterostructures, Electron Affinity, Common Anion rule, Calculation of Band Offset, Experimental methods.

4. **Electron States:** Effective mass approximation, Energy levels of electrons in quantum wells, Superlattice, Single heterojunction, Quantum wire and dot, energy levels of holes.

5. **Interaction:** Optical Interaction phenomena, Interaction in quantum wells, Excitons, Absorption.

6. **Transport Properties:** Transport Properties (10), Solution of transport equation for 2 DEG, mobility, high field velocity, quantum Hall Effect, ballistic transport.

7. **Structure and Principle of operation :** Of High mobility transport, resonant tunneling diode, quantum well laser, quantum well detector, modular and switch, optical bi-stable devices.

Total Class Hours = 75

Books:

1. Physics of Quantum Well Devices – B.R.Nag
2. Introduction to Nanoelectronics – V.V.Mitin, V.A. Kochelap and M.A. Stroscio
3. Physics of Low-dimensional semiconductors.- J.H.Davies
4. Electronic Transport in Mesoscopic Systems – S.Datta
5. Transport in Nanostructure – D.K.Ferry and S.M.Goodnick