INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE
Jadavpur, Kolkata – 700 032

Post B.Sc. Integrated Ph.D (Physical Sciences)

in collaboration with Jadavpur University

Course Structure

INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE

POST B.Sc. INTEGRATED Ph.D. PROGRAMME IN PHYSICAL SCIENCES

Course Structure for M.Sc.

Notes:

1. "L+T" means 3 hours of lecture are followed by 1 hour of tutorial
2. "P" means practicals
3. For every course, course credits are equal to the number of contact hours per week

First Year

Semester I

Course Number	*Course Title*	*L+T - P*
PH401	Classical Mechanics	3–0
PH403	Quantum Mechanics-1	3–0
PH405	Mathematical Methods-1	3–0
PH407	Electronics	2–6
PH409	Numerical Methods & Computer Programming	1–3

Total Contact Hours per week 21
Total Credits 21

Semester II

Course Number	*Course Title*	*L+T - P*
PH402	Electromagnetic Theory-1	3–0
PH404	Quantum Mechanics-II	3–0
PH406	Mathematical Mrthods-II	3–0
PH408	Statistical Mechanics	3–0
PH410	Physics Laboratory	0–6

Total Contact Hours per week 18
Total Credits 18

Second Year

Semester III

Course Number	*Course Title*	*L+T – P*
PH501	Electromagnetic Theory-II	3-0
PH503	Atomic & Molecular Physics	3–0
PH505	Condensed Matter Physics	3–0
	Elective -1	3–0
PH509	Research Project (With Seminar)	0–16

Total Contact Hours per week 28
Total Credits 28

Semester IV

Course Number	*Course Title*	*L+T - P*
PH502	Nuclear & Particle Physics	3–0
	Elective-II	3–0
	Elective-III	3–0
	Elective-IV	3–0
PH510	Research Project Continued (With seminar)	0–16

Total Contact Hours per week 28
Total Credits 28

DETAILED COURSE CONTENTS

FIRST YEAR: SEMESTER I

PH 401 Classical Mechanics

Newton's laws, generalised co-ordinates. Lagrange's principle of least action and equations. Conservation laws and symmetry. Integrable problems, elastic collisions and scattering. Small oscillations including systems with many degrees of freedom, rigid body motion. Hamilton's equations. Poisson brackets. Hamilton Jacobi theory. Canonical perturbation theory, Chaos.

1. Goldstein, H., Classical Mechanics, Second Edn, Narosa,1989.
2. Landau, L.D., and Lifshitz, E.M., Mechanics, Pergamon, 1976.
3. Rana N. ,and Joag, P.S., Classical Mechanics Tata McGraw-Hill, New Delhi, 1991.

PH 403 Quantum Mechanics-I

Vector spaces, linear operators, eigenvalue problems; postulates of quantum mechanics, Heisenberg uncertainty relations; time evolution; Schroedinger equation; harmonic oscillator; creation and annihilation operators; One dimensional problems – bound states, tunneling, scattering. The harmonic oscillator, analytical and operator approaches. Three dimensional problems. Symmetries, conservation laws, degeneracies, with examples. Infinitesimal rotations, angular momentum operators, commutation relations and their consequences. Separation of variables for a central force problem. Spherical harmonics. The hydrogen atom. Time independent perturbation theory, non-degenerate and degenerate cases. Fine and hyperfine structure of energy levels. Stark and Zeeman effects.

1. Modern Quantum Mechanics: J.J. Sakurai (1999) Revised Edition, Addison-Wesley
2. Quantum Mechanics: C. Cohen-Tannoudji, B. Diu and F. Laloe (1977)
Vol 1 and 2, Wiley-Interscience
3. Principles of Quantum Mechanics: R. Shankar (2010) 2nd edition, Springer
4. Introduction to Quantum Mechanics: D.J. Griffiths (2004) 2nd edition, Addison-Wesley

PH 405 Mathematacal Methods-1

Vectors: Definitions, dot product, cross product, vector fields, Differentiation, line integrals, surface integrals, Divergence Theorem, Stokes Theorem, Tensors(qualitative concepts), summation convention and co-ordinate transformation. Curvilinear Coordinates.

Linear algebra and Vector spaces: Matrices, Rank of a Matrix, Complex Inner Product Spaces, Orthogonal and Unitary Transformations, Eigenvalues and Eigenvectors and application, Change of Basis, Diagonalization of Matrices. Function spaces; Hilbert spaces; orthogonal expansions; operators in infinite dimensional spaces, Fourier series and Fourier transform, generalized functions; Dirac delta function,

Differential equation: Methods of solution, Laplace transformation method, Power series method, Fourier expansion methods. Orthogonal polynomials: Orthogonal polynomials, Legendre and Hermite polynomials, Sturm-Liouville Theory, Eigenfunction Expansions.

Elements of statistics: probability, random walk. Probability distributions

1. Mathematical methods for Physicist, Arfken and Weber, Academic, 1995
2. Mathews, J., and, R.L., Mathematical Methods of Physics, Benjamin, 1973.
3. Dennery, P., and Krzywicki, A., Mathematics for Physicists, Harper and Row, NY, 1967.
4. Wyld, H.W., Mathematical Methods for Physics, Benjam, 1976.

PH 407 Electronics

Circuit theory**:** lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks, node and loop analysis, Thevenin and Norton's theorem, time domain response of RL, RC and RLC circuits, frequency domain response, impedance, filters and transfer function.

Analog electronics: discrete devices, characteristics and operation - diode, Zener diode, LED, photodiode. Simple diode circuits. Bipolar junction transistor (BJT): biasing, h parameters, small and large signal response, amplifiers. Field effect transistors. Operational amplifiers - device properties, integrator, differentiator, RC active filter, negative and positive feedback, oscillators.

Digital electronics**:** logic gates, truth table, multiplexer, combinatorial circuits, flip-flop, counters, programmable logic devices, microprocessors.

Physics of Semiconductor devices: Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky Barriers, Miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR; p-n-p-n switch, SCR; Unijunction transistor (UJT); Programmable Unijunction transistor (PUT), Solid state detectors (Si and HPGe).

Electronics Laboratory

1. Elements of Electronic Instrumentation and Measurement, Carr, Pearson
2. Electronic Instrumentation and Measurement, Zbar, McGraw Hill
3. Digital Logic and Computer Design, Mano , Pearson
4. Digital computer electronics, Malvino and Brown, TMH
5. Digital Principles, Leach and Malvino, TMH
6. Digital Circuits, Vol-I and II, D. RoyChaudhuri, Platinum publishers
7. Basic Electronics: A Text Lab Manual, Zbar, TMH
8. J.D.Ryder, Electronics fundamental and application.PHI.

PH 409: Numerical Methods and Computer Programming

Programming Language

Basic knowledge of C or Fortran 90 – Data statements, Logical and Arithmetic expressions, Operators, I-O statements, Implementation of Loops, Control Statements, Functions and Subroutines, Array manipulation, Processing Strings and Characters, Format Specifications, File processing, Derived types, Pointers and Structure Data Type.

Familiarization with Linux based operating system, development of simple C or Fortran programs, compilation and execution.

Numerical Method

Root finding of equations having numerical coefficients using Successive Bi-section and Newton Raphson method, Basic ideas of Interpolation – Newton's forward and backward interpolation, Lagrange method for unequal intervals, Numerical integration of a definite integral using Trapezoidal and Simpson's one-third rule, Statistical Description of Data, Fast Fourier Transform, Fourier and Spectral Applications, Numerical solution for a set of coupled ordinary differential equation –, Initial Value Problem: Runge Kutta Method, (ii) Boundary Value Problem: Relaxation Technique, ShootingMethod, Partial Differential Equations (PDE): (i) Elliptic PDE – Static Boundary Value Problems, (ii) Parabolic PDE – Time Evolution or Dynamic Initial Value Problems, (iii) Hyperbolic PDE – Wave Propagation Problem

1. Applied Numerical Analysis: Gerald and Wheatley, Pub:Pearson
2. An introduction to computational physics: Tau Pang, Cambridge Univ. Press
3. Introduction to Numerical Methods and FORTRAN Programming: Thomas Richard McCalla, John Wiley and Sons Ltd

COURSE CONTENTS

FIRST YEAR: SEMESTER II

PH402 Electromagnetic Theory 1

Coulomb law and electrostatics, Laplace and Poisson equations, uniquenesstheorem, boundary-value problems, method of images, dielectrics, steady currents; and magnetostatics, time-varying fields, Maxwell's equations, electromagnetic waves, partial polarization, Lorentz force, Poynting theorem. gauge transformations and gauge invariance, electromagnetic potentials, wave propagation in conductors and dielectrics, Lorentz theory of dispersion, complex refractive index.

1. D. J. Griffiths, Introduction to Electrodynamics
2. Jackson, J.D., Classical Electrodynamics, Third Edn, John Wiley.
3. L. D. Landau and E. M. Lifshitz, Classical theory of Fields
4. Panofsky, W.K.H., and Phillips, M., Classical Electricity and Magnetism, Second Edn,.

PH 404 Quantum Mechanics II

Time dependent perturbation theory. Fermi golden rule. Transitions caused by a periodic external field. Dipole transitions and selection rules. Decay of an unstable state. Born cross section for weak potential scattering. Adiabatic and sudden approximations. WKB method for bound states and tunneling. Scattering theory: partial wave analysis, low energy scattering, scattering length, born approximation, optical theorem, Levinson's theorem, resonances, elements of formal scattering theory. Minimal coupling between radiation and matter, diamagnetism and paramagnetism of atoms, Landau levels and Aharonov Bohm effect. Addition of angular momenta, Clebsch Gordon series, Wigner Eckart theorem, Lande's g factor. Many particle systems: identity of particles, Pauli principle, exchange interaction, bosons and fermions. Second quantization, multielectron atoms, Hund's rules. Introduction to Klein Gordon and Dirac equations, and their non relativistic reduction, g factor of the electron.

1. Modern Quantum Mechanics: J.J. Sakurai (1999) Revised Edition, Addison-Wesley
2. Quantum Mechanics: C. Cohen-Tannoudji, B. Diu and F. Laloe (1977)
Vol 1 and 2, Wiley-Interscience
3. Principles of Quantum Mechanics: R. Shankar (2010) 2nd edition, Springer
4. Introduction to Quantum Mechanics: D.J. Griffiths (2004) 2nd edition, Addison-Wesley

PH406 Mathematical Methods II

Functions of a complex variable: Limits, continuity, Differentiations, Cauchy-Reimann equations, Complex integrations, Residues and Cauchy residue theorem. Evaluation of real, definite integrals, principal values, Riemann surfaces, conformal mapping, analytic continuation.

Partial differential equation: Examples, chain rule, Laplace equation in Cartesian and polar form, one and two dimensional wave equations , Green's functions.

Introduction to finite and continuous groups. Group representations and operations on them. Permutation group and its representations. Lie groups and Lie algebras. SU(2), SU(3) and SU(N) groups.

1. Mathematical methods for Physicist, Arfken and Weber, Academic, 1995
2. Mathews, J., and, R.L., Mathematical Methods of Physics, Benjamin, 1973.
3. Dennery, P., and Krzywicki, A., Mathematics for Physicists, Harper and Row, NY, 1967.
4. Wyld, H.W., Mathematical Methods for Physics, Benjam, 1976.

PH408 Statistical Mechanics

Review of Thermodynamics, Basic principles of statistical mechanics and its application to a few simple systems. Probability theory, fundamental postulate, phase space,Liouville's theorem, ergodicity, microcanical ensemble, connection with thermodynamics, canonical ensemble, classical ideal gas, harmonic oscillators, paramagnetism,Ising model, physical applications to polymers, biophysics. Grand canonical ensemble, thermodynamic potentials, Maxwell relations, Legendre transformation, introduction to quantum statistical mechanics, Fermi, Bose and Boltzmann distribution, Bose condensation, photons and phonons, Fermi gas, classical gases with internal degrees of freedom, fluctuation, dissipation and linear response, Monte Carlo and molecular dynamics methods.

1. Pathria, R.K., Statistical Mechanics, Butterworth Heinemann, Second Edn, 1996.
2. Reif, F., Fundamentals of Statistical and thermal Physics, McGraw Hill, 1965.
3. Huang, K., Statistical Mechanics,
4. Bhattacharjee, J.K., Statistical Mechanics: Equilibrium and non-equilibrium aspects.
5. J P Sethna, J.P., Statistical Mechanics: Entropy, Order Parameters and Complexity, Univ Press, 2006.

PH410 Physics Laboratory

Laboratory courses have been designed to inculcate a hands-on approach towards experimental physics.

COURSE CONTENTS

SECOND YEAR: SEMESTER III

PH 501 Electromagnetic Theory-II

Special relativity, Minkowski space and four vectors, concept of four-velocity, four acceleration and higher rank tensors, relativistic formulation of electrodynamics, Maxwell equations in covariant form, gauge invariance and four-potential, the action principle and electromagnetic energy momentum tensor. Liénard-Weichert potentials, radiation from an accelerated charge, Larmor formula, bremsstrahlung and synchrotron radiation, multipole radiation, dispersion theory, radiative reaction, radiative damping, scattering by free charges; applications to wave-guides, fibres and plasmas.

1. D. J. Griffiths, Introduction to Electrodynamics
2. Jackson, J.D., Classical Electrodynamics, Third Edn, John Wiley.
3. L. D. Landau and E. M. Lifshitz, Classical theory of Fields
4. Panofsky, W.K.H., and Phillips, M., Classical Electricity and Magnetism, Second Edn,.

PH 503 Atomic & Molecular Physics

Atomic physics: One electron atoms - spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect. Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions. Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.

Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structuremolecular orbital and valence bond theories.

Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.

Cold atoms: Doppler cooling, magneto-optical trap, ion traps, dipole force, evaporative cooling, optical lattice. Collective effects - Feshbach tuning of interactions, Bose condensation of alkali atoms, BCS-BEC crossover, the unitary Fermi gas. Imaging cold atoms.

Computing with atoms: qubits and their properties, entanglement, quantum logic gates, decoherence and error correction.

References:

1. C. Foot, Atomic physics.
2. D. Budker, Atomic physics.
3. B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules.

4. M. Inguscio and L. Fallani: Atomic physics, ultracold matter.
5. M. Weidemuller, C. Zimmermann: Cold atoms and molecules.
6. K. Levin, A. L. Fetter and D. M. Stamper-Kurn, Ultracold bosonic and fermionic gases.

PH 505 Condensed Matter Physics

Drude model, Sommerfeld model, crystal lattices, reciprocal lattice, x-ray diffraction, Brillouin zones and Fermi surfaces, Bloch's theorem, nearly free electrons, tight binding model, selected band structures, semiclassical dynamics of electrons, measuring Fermi surfaces, cohesive energy, classical harmonic crystal, quantum harmonic crystal, phonons in metals, semiconductors, diamagnetism and paramagnetism, magnetic interactions. Superconductivity

1. Ashcroft, N.W., and Mermin ,Physics, Holt-Saunders International, NY, 1976.
2. Kittel, C., Introduction to Solid State Physics, 5th/6th/7th editions, Wiley International.

Elective -1 (Any one)

PH 513 Advanced Statistical Physics

Background: order parameters, mean field theory, phase transitions, Landau-Ginzburg theory, estimating fluctuations. The scaling hypothesis.
Renormalisation group in classical systems: Hubbard-Stratonovich transformation, gaussian functional integrals, rederiving mean field theory, self-consistent field approximation. Real space RG: Kadanoff construction, application to the Ising model.
Momentum shell RG: diagrammatic perturbation theory - first and second order, epsilon expansion, fixed points. Two dimensional solids, XY model.
Renormalisation group in quantum systems: path integrals for fermions. One dimension: quartic perturbations, RG at tree level, RG at one loop. RG in higher dimensions: the one loop beta function, fixed points, Kohn-Luttinger effect. 1/N expansion and Fermi liquid theory.
Equilibrium dynamics: conserved and broken symmetry variables, spin systems, hydrodynamics of simple fluids, dynamic critical phenomena.
Non equilibrium phenomena: Boltzmann equation, Langevin and Fokker-Planck descriptions.
Stochastic thermodynamics: non-equilibrium work theorems (Jarzynski, Crooks..), nonequilibrium steady states, stochastic heat engines, examples from colloidal particles, molecular motors.

References:

1. M. Kardar, Statistical Mechanics of Fields.
2. P. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics.
3.R. Shankar, Renormalization-Group Approach to Interacting Fermions, Rev. Mod. Pays 66, 129 (1994).
4. B. Halperin and P. Hohenberg, Theory of Dynamical Critical Phenomena, Rev. Mod. Phys. 49 (1977).
5. G. F. Mazenko, Non-equilibrium Statistical Mechanics.
6. U. Seifert, Stochastic Thermodynamics, Fluctuation Theorems.., Rep. Prog. Phys. 75, 126001 (2012).
7. K. Sekimoto, Stochastic Energetics.

PH 515 Quantum Field Theory -1

Non-relativistic quantum field theory: quantum mechanics of many particle systems; second quantisation; Schrodinger equation as a classical field equation and its quantisation; inclusion of inter-particle interactions in the first and second quantised formalism
Irreducible representations of the Lorentz group, connection to quantum fields
Symmetries and conservation laws: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations; associated conserved charges
Free Klein-Gordon equation: classical action and its quantisation; spectrum; Feynman rules for computing n-point Green's function of elementary and composite operators.
Interacting Klein-Gordon field; Feynman rules for computing Greens functions; physical mass of the particle from the analysis of two point Greens functions; S-matrix and its computation from n-point Greens functions; relating S-matrix to cross-section.
Quantisation of free Dirac fields: spectrum; Feynman rules
Quantisation of free electromagnetic field: role of gauge invariance; gauge fixing; physical state condition; spectrum; Feynman rules
Quantum electrodynamics: coupling Dirac field to electromagnetic field; gauge invariance; quantisation; Feynman rules for computing Green's function; Spectrum and S-matrix from the Greens function.

References:

1. M. E. Peskin and D. V. Schroeder, Quantum Field Theory.
2. C. Itzykson and J. B. Zuber, Quantum Field Theory.
3. J. D. Bjorken and S. Drell, Relativistic Quantum Fields.
4. S. Weinberg, Quantum Field Theory (Volume I and II).

PH 517 Physics of Materials

Introduction to material science; building crystals from atoms, structure property relationship, Electronic structure and phonons, Stability of structures: (a) thermodynamic stability (b) dynamic stability, Material properties: Mechanical; electrical; optical; magnetic and thermal, Defects, non crystalline solids and finite structures.
Types of materials: Metals, semiconductors, ceramics, polymers, composites, multi-functional materials.
Characterization techniques: Experimental: X-ray & neutron diffraction, electron microscopy, scanning probe microscopy, spectroscopy and surface analysis techniques, optical spectroscopy, magnetic spectroscopy
Computational: multi-scale modeling

Recommended Reading:
1. Atomic and Electronic Structure of Solids, E. Kaxiras, Cambridge

Depending on the interest more electives will be included

COURSE CONTENTS

SECOND YEAR: SEMESTER IV

PH 502 Nuclear & Particle Physics

Radioactive decay, subnuclear particles. Binding energies. Nuclear forces, pion exchange, Yukawa potential. l.i sospin, neutron and proton. Deuteron. Shell model, magic numbers. Nuclear transitions. Selection rules. Liquid drop model. Collective excitations. Nuclear fission and fusion. Beta decay. Neutrinos. Fermi theory, parity violation, V-A theory. Mesons and baryons. Lifetimes and decay processes. Discrete symmetries, C, P, T and G. Weak interaction transition rules. Strangeness, K mesons and hyperons. Composition of mesons and baryons, quarks and gluons.

1. Povh, B., Rith, K., Scholz, C., and Zetsche, F., Particles and Nuclei,An Introduction to Physical Concepts, Second Edn, Springer, 1999.
2. Krane, K.S., Introductory Nuclear Physics, John Wiley and Sons, NY, 1988.
3. Griffiths, D., Introduction to Elementary Particles John Wiley and Sons, NY, 1987.
4. Perkins, D.H., Introduction to High Energy Physics, Third edition, Addison-Wesley,, 1987

Elective -II
Elective -III
Elective -IV

Any of the following three Courses

PH512 Quantum Field Theory -II

Gaussian integrals & power series expansion; Path integrals in Quantum Mechanics & Feynman diagrams; Classical Field Theory, symmetries and Noether's theorems; Functional differentiation & integration (free scalar, vector & spinor); Quantization of vector fields (Fadeev Popov) ; Green functions in functional integrals; Interacting scalar field theories; Dyson-Schwinger & Ward identities; Evaluation of Feynman diagrams (using dimensional regularization); Representation of Poincare group & classification of fields according to spin; Quantum Electrodynamics (QED) – 1-loop renormalization; Beta function and Landau pole in QED

PH514 Particle Physics

Experimental aspects of particle physics: fixed target and collider experiments, particle detectors.

Symmetries : charge conjugation, parity, time reversal, isospin and SU(2), motivation for the quark model and SU(3)

Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths

Quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.

Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics.

Introduction to weak interactions: parity violation, (V-A) theory, pion and muon decay, neutrino scattering.

The gauge theory of electroweak interactions: Glashow-Salam-Weinberg model, applications of the model, neutral current phenomena, The physics of W-and Z-bosons, physics of the Higgs boson.

PH 522 Advanced Condensed Matter Physics

Born-Oppenheimer Approximation, Review of one-electron band theory. Effects of electron-electron interaction:Hartree–Fock approximation, exchange and correlation effects, density functional theory, Fermi liquid theory, elementaryexcitations,quasiparticles. Dielectric function of electron systems, screening, plasma oscillation. Optical properties of metals and insulators, excitons. The Hubbard model, metal-insulator transition. Review of harmonic theory of lattice vibrations. Electron-phonon interaction – phonons in metals, mass renormalization, effective interaction between electrons, polarons.Transport phenomena, Boltzmann equation, electrical and thermal conductivities, thermo-electric effects. Superconductivity–phenomenology, Cooper instability, BCS theory, Ginzburg-Landau theory.

1. Ashcroft, N.W., and Mermin, D , Solid State Physics
2. Madelung, O., Introduction to Solid State Theory, Springer Verlag,
3. Jones, W., and March, N.H., Theoretical Solid State Physics

PH 524 Nanoscale Materials

Introduction to different nanosystems and their realization; electronic properties of quantum confined systems: quantum wells, wires, nanotubes and dots. Optical properties of nanosystems: excitons and plasmons; photoluminescence, absorption spectra, vibrational and thermal properties of nanosystems; zone folding

1. Nanostructures: Theory an Modelling, C. Delerue and M Lannoo, (Springer, 2006)
2. Physical Properties of Carbon Nanotubes, Saito, R., Dresselhaus, G., and Dresselhaus, M.S.

PH 530 Electronic Structure and Properties of Materials

Review of QM: variational method, identical particles, many fermion wave functions.
First-principles Hamiltonian and Born-Oppenheimer approximation.
Treating electron-electron interactions: Hartree-Fock approximation, exchange energy, correlation energy.
Density functional theory: Thomas-Fermi method, Hohenberg-Kohn theorems, Levy constrained search formulation, Kohn-Sham formulation, exchange-correlation energy, LDA and GGA functionals, spin density functional theory.

Solution of the Kohn-Sham equations, basis sets – Linear Combination of Atomic Orbitals (LCAO), Augmented Plane Waves (APW), Korringa-Kohn-Rostoker Method, Linear Methods (LAPW, LMTO)
Solution of Hartree Fock Equations: Spin-restricted calculations, Roothan equations. Spin unrestricted calculations.
Pseudopotentials and PAW in conjunction with plane waves.
Structure optimisation, Hellman-Feynman theorem.
Simple practical applications: band structure of standard solids, metals and semiconductors, optimisation of lattice constants, cohesive energies and other simple properties.

Advanced topics: hybrid functionals, van der Waals interactions, density functional perturbation theory, phonon band structure, electron-phonon coupling.

Correlated electrons: Mott physics: electron localisation, magnetic order, doped phase, physics in the cuprates.
Kondo systems: physics of the single impurity, dense systems
Kondo and Anderson lattice, heavy fermions, quantum criticality.
Metallic magnets: ferromagnetism in strongly repulsive systems, the transition metals, spin-fermion systems, the double exchange model, the classical Kondo lattice.

1. E. Kaxiras, Atomic and electronic structure of solids.
2. R. M. Martin, Electronic structure.
3. A. Szabo and N. S. Ostlund, Modern Quantum Chemistry.
4. D. Sholl and J. A. Steckel, Density functional theory.

PH516 General Relativity and Cosmology

1. Diffeomorphism, Covariant and Contravariant tensors under general coordinate transformations, Parallel transport, Affine connection, Riemann curvature tensor

2. Einstein's equation, Principle of Equivalence, Energy momentum tensor, Spherically symmetric solution, Birkhoff's theorem, Schwarzschild geometry, Tests of Einstein's equation, Perihelion precession, Bending of light, gravitational redshift

3. Reissner Nordstrom geometry, Kerr Geometry, Black hole Physics, Kruskal-Szekers coordinate, Penrose diagramme, Surface gravity, Hawking temperature,
Hawking radiations, Elements of Black hole mechanics

4. Cosmological principle, Friedman-Robertson-Walker metric, equation of state, Hubble constant, Inflationary cosmology, Dark energy

1. Gravitation and Cosmology -- S. Weinberg
2. Gravitation -- R. Wald
3. Gravitation -- Hartle
4. Gravitation -- Padmanabhan

Annexure-I :

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PH 518 Light-Matter Interactions

I. Light-Atom Interactions
I.1 Two-level atoms
Semi-classical treatment, dipole approximation, rotating-wave approximation (RWA), density matrix approach, spontaneous emission, homogeneous and inhomogeneous line broadening, weak- and strongcoupling regimes, Rabi oscillations, atomic coherence, susceptibility, absorption and dispersion, optical Bloch equation
I.2 Three-level atoms
Lambda, Vee and Cascade systems, semi-classical treatment, polarizability, Raman effect, pump-probe experiment, dark state resonance, electromagnetically induced transparency (EIT), dispersion, slow and fast light, stimulated Raman adiabatic passage (STIRAP)
II. Dressed State Formalism
Quantized radiation fields, two-level atom interacting with a single-mode quantized field, Jaynes-Cummings model
III. Laser Cooling and Trapping
III.1 Doppler cooling
Mechanical effects of light, moving two-level atoms interacting with light, Doppler shifts, Lamb dip spectroscopy, optical molasses, dissipative light force, fluctuation-diffusion of atomic motion in light fields, Doppler cooling, Doppler limit
III.2 Sub-Doppler cooling
Dispersive or reactive light forces, light shifts, Sisyphus cooling, gradient forces, velocity selective coherent population trapping, optical lattices
IV. Elements of Quantum Optics
Hanbury Brown-Twiss experiment, photon-photon correlations, bunching, anti-bunching, optical theory of coherence, coherent states, squeezed states, cavity QED, Purcell effect, collapse and revival of Rabi oscillations, vacuum field Rabi splitting, atom-photon entanglement, a brief introduction to quantum information science.

1. Atom-Photon Interactions - Basic Processes and Application, C. Cohen-Tannoudji, J. Dupont-Roc, G. Grynberg, Wiley-VCH (2004)

2. Introduction to Quantum Optics - From the Semi-classical Approach to Quantized Light, G. Grysberg, A. Aspect and C. Fabre, Cambridge, (2010)

3. "Atomic Motion in Laser Light", Les Houche (Session LIII - 1990) Lecture by C. Cohen-Tannoudji, in "Fundamental Systems in Quantum Optics" Elsevier Scince Publishers B. V.,(1992).

4. Laser Cooling and Trapping, H. J. Metcalf and P van der Straten, Springer (1999).

5. Quantum Theory of Optical Coherence: Selected Papers and Lectures, Roy J. Glauber, Wiley VCH (2007)

Depending on the interest more electives will be included

Annexure-I :