Presidency University
Department of Physics
Syllabus for Post Graduate Teaching
(2022-23 session onward)

Semester	***Subject***	***Category***	***Marks****	***Code***	***Credit***
I Credit 20 Marks 250	Mathematical Methods	Theoretical	35 + 15	PHYS0701	4
	Classical Mechanics: Particles & Fields	Theoretical	35 + 15	PHYS0702	4
	Quantum Mechanics-I	Theoretical	35 + 15	PHYS0703	4
	PG Laboratory-I	Sessional	50	PHYS0791	4
	PG Laboratory-II	Sessional	50	PHYS0792	4
II Credit 20 Marks 250	Statistical Mechanics	Theoretical	35 + 15	PHYS0801	4
	Quantum Mechanics-II	Theoretical	35 + 15	PHYS0802	4
	Condensed Matter Physics	Theoretical	35 + 15	PHYS0803	4
	PG Laboratory-III: Computational Techniques	Sessional	50	PHYS0891	4
	PG Laboratory-IV	Sessional	50	PHYS0892	4
III Credit 20 Marks 250	Atomic and Molecular Spectroscopy	Theoretical	35 + 15	PHYS0901	4
	Classical Electrodynamics	Theoretical	35 + 15	PHYS0902	4
	Special-I (Choice Based) (Any one of the following two)				4
	A. Advanced Condensed Matter Physics-I	Theoretical	35 + 15	PHYS0903A	
	B. Nuclear & Particle Physics-I	Theoretical	35 + 15	PHYS0903B	
	Special-II (Choice Based) (Any one, continuation of Spl.I)				4
	A. Advanced Condensed Matter Physics-II	Theoretical	35 + 15	PHYS0904A	
	B. Nuclear & Particle Physics-II	Theoretical	35 + 15	PHYS0904B	
	Elective (Choice Based)** (Any one of the following three)				4
	A. Project-I	Sessional	50	PHYS0991A	
	B. Quantum Optics and Laser Physics	Sessional	50	PHYS0991B	
	C. Electronic Materials and Devices	Sessional	50	PHYS0991C	
IV Credit 20 Marks 250	**Special-III** (Choice Based) (Any one, continuation of Spl.II)				4
	A. Advanced Condensed Matter Physics-III	Theoretical	35 + 15	PHYS1001A	
	B. Nuclear & Particle Physics-III	Theoretical	35 + 15	PHYS1001B	
	Special-IV(Choice Based) (Any one, continuation of Spl.III)				

	A. Advanced Condensed Matter Physics-IV	Theoretical	35 + 15	PHYS1002A	4
	B. Nuclear & Particle Physics-IV	Theoretical	35 + 15	PHYS1002B	
	Special-V(Choice Based) (Any one, continuation of Spl.IV)				4
	A. Advanced Condensed Matter Physics-V Laboratory	Sessional	50	PHYS1091A	
	B. Nuclear & Particle Physics-V Laboratory	Sessional	50	PHYS1091B	
	Grand viva on General Physics	Sessional	50	PHYS1092	4
	Elective (Choice Based)** (Any one of the following three)				4
	Project-II (continuation of Project-I)	Sessional	50	PHYS1093A	
	Physics of nanostructured materials	Sessional	50	PHYS1093B	
	General Theory of Relativity	Sessional	50	PHYS1093C	
	Nonlinear Physics	Sessional	50	PHYS1093D	
Grand Total Marks 1000				Total Credit	80

*Theoretical papers have 35 marks for end-semester examination and 15 marks for continuous evaluation. Sessional papers have consolidated 50 marks for continuous/dynamic evaluation

** Not all electives will be offered every year

PHYS0701: Mathematical Methods (50 Lectures)

Complex Analysis [16]: Complex variables, The Riemann Sphere: Stereographic projection, A metric on the extended plane. Analytic functions: The Cauchy-Riemann conditions, Derivatives of analytic functions. Power series as analytic function: Radius and circle of convergence, Analytic continuation; Behaviour on the circle of convergence; Lacunary series. More on analytic functions: Cauchy integral theorem; Singularities: Simple pole, Residue at a pole, Multiple pole, Essential singularity, Accumulation points. Contour integration: Cauchy's Residue Theorem; Dirichlet Integral: Cauchy principal value, the `i \epsilon'-prescription for a singular integral; Residue at infinity. Multivalued functions: Branch points and Branch cuts, Types of branch points, Contour integral in the presence of branch points. Application of complex variables: Complex potentials, application of conformal transformations.

Vector Spaces [6]: Basis sets and dimensionality, Dual of a linear space, Gram-Schmidt orthonormalization; Cauchy-Schwarz inequality, Triangle inequality. Infinite dimensional vector spaces: spaces of square-summable sequences and square integrable functions, The space of square-integrable functions: Continuous basis, L_2 functions and Fourier transforms. Hilbert space, Linear manifolds and subspaces. Linear operators on a vector space: Domain, range and universe, Linear operators, norm and bounded operators, Adjoint of an operator, Derivative operator in L_2, Nonsymmetric operators. Useful operator identities: Perturbation series for an inverse operator, Hadamard's Lemma, The Baker-Campbell-Hausdorff formula.

Differential Equations [10]: Orthogonal Polynomials: Orthogonality and completeness, expansion and inversion formula, Parseval's theorem, Uniqueness and explicit representation, recursion relation.
Classical orthogonal polynomials: Polynomials of hypergeometric type, hypergeometric differential equation, Rodrigues formula and generating function, Hermite polynomials, generalized Laguerre polynomials, Jacobi polynomials, Legendre polynomials. Green's function: Green's function for an ordinary differential operator, Poisson's equation in three dimensions.

Solution of Poisson's equation, Connection with the Coulomb potential, Determination of Green's function in d-dimensional space, Power counting and divergence problems, Green's functions in 2-dimensions.

Integral Transforms [8]: Laplace transform: Definition, transforms of some simple functions, the convolution theorem, Laplace transforms of derivatives, The inverse Laplace transform: The Melin formula, LCR circuit under a sinusoidal applied voltage, Bessel functions and its Laplace transform.

Fourier Transform: Expansion of non-periodic functions: Fourier transform and inverse Fourier transform, Parseval's formula, Fourier transform of the delta function, the convolution theorem, The Fourier transform operator in L_2 : The adjoint of an integral operator, Unitarity of the Fourier transformation. Solution of partial differential equations using integral transforms.

Group Theory [10]
Preliminaries, Different mappings, isomorphism, homomorphism, automorphism. Representation of finite discrete groups, construction of multiplication table, character table,. Invariant subspaces, reducibility, irreducibility, equivalence of representation. Schur's lemma, unitary and orthogonal representations. Permutation group, Young Tableux.

Infinite continuous groups: Lie groups and Lie algebras – one dimensional translation group, orthogonal group: O(2), SO(2), O(3), SO(3), SO(4), Unitary group: U(1), U(2), SU(2), SU(1,1). Representation of rotations by SU(2) matrices, connection between the groups SO(3) and SU(2).
Parameter space: SU(2), SO(3), SO92), SU(1,1).
Relativistic groups: Lorentz group SO(1,3), Poincare group.

References:

1. Methods of Theoretical Physics - P. Morse and H. Feshbach, Feshbach publishing.
2. Matematical Methods in the Physical Sciences - M. L. Boas, Wiley.
3. Mathematical Methods for Physicists - G. B. Arfken, H. J. Weber and F. E. Harris, Academic Press(Elsevier).

4. Mathematical Methods for Physics and Engineering-K.F. Riley, M. P. Hobson and S. J. Bence, Cambridge University Press.
5. Schaum's Outline of Mathematics for Physics Students-Robert Steiner, Philip Schmidt, McGraw-Hill Education.

PHYS0702: Classical Mechanics: Particles and Fields (50 Lectures)

Preliminaries [10]
Variational principle and Lagrange's equations of motion – simple applications, Lagrangian for mechanical systems with dissipation and for systems subject to non-holonomic constraints, Hamiltonian formulation, Small Oscillations.

Rigid Body [12]
Kinematics, Euler angles, Infinitesimal rotation, Motion of heavy symmetrical top with one point fixed, other applications.

Canonical Transformation and Hamilton-Jacobi Theory [14]
Generating function, Poisson bracket, Canonical invariants, Hamilton-Jacobi theory, Action angle variables, Kepler problem.

Continuous Systems and Fields [10]
Introduction to tensors, Lagrangian and Hamiltonian formulation for continuous systems, Symmetry and conservation principles – Noether's Theorem, Classical field theory.

Nonlinear Dynamics and Classical Chaos [4]
Phase space dynamics, Stability analysis, Lyapunov exponent, Bifurcation..examples

References:

1. Classical Mechanics - Herbert Goldstein, Addison-Wesley.
2. Introduction to Classical Mechanics:With problems & amp; Solutions-David J. Morin, Cambridge University Press.
3. Classical Mechanics- John R. Taylor, UniversityScience Books.
4. Classical Mechanics - H. C. Corben, Dover Books on Physics.
5. Classical Mechanics - R. Douglas Gregory, Cambridge University Press.
6. Mechanics – Arnold Sommerfeld, Academic Press.

PHYS0703: Quantum Mechanics-I (50 Lectures)

Axiomatic Formulation of Quantum Mechanics [10]
State vectors and linear operators in Hilbert space, Dual space, Dirac notation, Matrix representations, Compatible observables, Schroedinger and Heisenberg pictures.

Symmetries [5]
Conservation laws and the degeneracy associated with symmetry. Continuous symmetries – space and time translations, Rotations, Discrete symmetries – parity and time reversal.

Angular Momentum [10]
Angular momentum algebra, Orbital angular momentum and spin. Addition of two angular momenta, Clebsch-Gordon coefficients, irreducible spherical tensor operators, Wigner-Eckart theorem.

Approximate methods [25]
A. Time-independent perturbation theory: Non-degenerate and degenerate systems. Applications – corrections to Hydrogen atom spectra due to relativistic electrons, spin-orbit coupling, Zeeman effect, Stark effect.

B. Variational method and its applications (to Helium, for example). WKB method: Construction of wave function, correction formula, Applications: quantum tunneling through a barrier, e.g. in radioactive alpha particle decay. Tunneling probability.

C. Time dependent perturbation theory: Intensity of spectral lines and transition probability, selection rule, constant and harmonic perturbations – Fermi's Golden Rule, approximations, Rabi oscillations.

D. The Adiabatic Theorem and Adiabatic Approximation, Geometric Phase and the Aharonov-Bohm effect.

References:

1. Modern Quantum Mechanics: J. J. Sakurai and J. J. Napolitano, Pearson

2. Elements of Quantum mechanics: B. Dutta-Roy, New Age International Publishers

3. Lectures on Quantum Mechanics (2nd Ed.) : Ashok Das

4. Introduction to Quantum Mechanics: David J Griffiths, Pearson

5. Introduction to Quantum Mechanics: B. H. Bransden and C. J. Joachain, Pearson Edn.

PHYS0791: PG Laboratory-I

The Following Experiments are part of the lab

1. Lande 'g' factor of DPPH using electron spin resonance spectrometer
2. Performance of high pass and low pass filters
3. Michelson's Interferometer
4. Saturation magnetization of ferromagnetic substance using hysteresis loop tracer
5. Characteristics of optical fibre

PHYS0792: PG Laboratory-II

A] Experiments
1. Muon detector
2. Noise Fundamentals
3. Fabry Perrot interferometer

B] Data Analyses and Statistical Techniques
1. Uncertainties in measurements: classification, reporting, propagation.
2. Estimates of mean and error, chi-square test.
3. Least square fit, goodness of fit, hypothesis testing.
4. Normal and Poisson distribution.
5. Plotting of data and preliminary analyses.

PHYS0801: Statistical Mechanics (50 Lectures)

Fundamentals of Statistical Mechanics [7]
Introduction: thermalization, ergodicity, Microcanonical Ensemble; Entropy and the Second Law; Temperature; Canonical Ensemble; Energy Fluctuations; Chemical Potential; Grand Canonical Ensemble, applications. Equivalence of ensembles : examples.

Classical and Quantum Gases [20]
Classical Partition Functions; Ideal Gas; Equipartition; Maxwell Distribution; Diatomic Gas; Interactions; van der Waals Equation of State; Cluster Integrals and Mayer-Ursell Expansion, Density of States; Applications, Density matrix formalism, Bose-Einstein Distribution and Bose-Einstein Condensation (applications); Fermi-Dirac Distribution, ideal Fermi gas, ideal Bose Gas, Applications. Landau levels, relativistic statistical mechanics.

Phase Transitions [18]
van der Waals equation revisited; Ising Model; Exact solution in one-dimension, Mean Field Theory; Critical Exponents; Low Temperature Expansion and Peierls Droplets; High Temperature Expansion; Landau Theory.

Nonequilibrium statistical physics [5]
Brownian motion, Langevin approach, Diffusion, Kinetics of magnetic relaxation.

References:

1. Statistical Mechanics (4^{th} Ed.): R. K. Pathria, Academic Press
2. Statistical Mechanics (2^{nd} Ed.): Kurson Huang, Wiley
3. Statistical Mechanics : R. P. Feynman, Levant
4. An Introductory Course of Statistical Mechanics: Palash B Pal, Narosa
5. Intermediate Statistical Mechanics, J. K. Bhattacharjee, Kindle Edn.

PHYS0802: Quantum Mechanics-II (50 Lectures)

Scattering theory [20]
Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Towwnsend effect; Scattering by a rigid sphere and square well; Regge poles, Coulomb scattering; Born approximation; Formal theory of scattering — Green's function in scattering theory; Lippman-Schwinger equation.

Identical Particles [5]
Identical particles, symmetry under interchange, wave functions for bosons and fermions. Slater determinant.

Relativistic Quantum Theory [25]
Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles, Preliminaries of free Quantum Field Theory, Dirac 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, Bilinear covariants and their transformation under parity and infinitesimal Lorentz transformation, Weyl representation and chirality projection operators, Quantization of spinor fields.

References:

1. Modern Quantum Mechanics: J. J. Sakurai and J. J. Napolitano, Pearson
2. Elements of Quantum mechanics: B. Dutta-Roy, New Age International Publishers
3. Lectures on Quantum Mechanics (2^{nd} Ed.) : Ashok Das
4. Introduction to Quantum Mechanics: David J Griffiths, Pearson
5. Introduction to Quantum Mechanics: B. H. Bransden and C. J. Joachain, Pearson Edn.
6. Quantum Field Theory in a Nutshell: A. Zee, Levant Books
7. A First Book on Quantum Field Theory: Amitabha Lahiri and Palash B Pal, Narosa

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PHYS0803: Condensed Matter Physics (50 Lectures)

Electron States and Band Theory of Solids [10]
Reciprocal lattice, Brillouin zone, Diffraction from periodic structure, Electron States in Crystals, Bloch's theorem (with proof), General properties of Bloch functions, Boundary Conditions in a finite Crystal. Density of states. Electron Band calculations: The Tight Binding Approximation and Wannier Functions, the Nearly Free Electron Approximation and the k.p Theory. Examples of band Structures (Si, Ge, GaAs& Zn). Fermi Surfaces. Cyclotron Resonance and Determination of Effective Masses.

Dynamics of Atoms in Crystals and Phonons [10]
The Potential, The Harmonic Approximation, The Equation of Motion, The

Dynamical Matrix, Normal Modes of a One Dimensional Monatomic Bravais Lattice, Normal Modes of a One Dimensional Monatomic Bravais Lattice with a Basis, Normal Modes of Two and Three Dimensional Monatomic Bravais Lattices. Inelastic Neutron Scattering by Phonons. The Density of States, The Thermal Energy of a Harmonic Oscillator, Lattice Specific Heat Capacity, The Debye theory, Anharmonic effects in Crystal: Project work on the measurement of heat capacity in solids at low temperature.

Dielectric and Optical Properties of Solids [6]
Phenomenological Theory: Maxwell's Equations, Traveling Waves, Dielectric function – a Harmonic oscillator model, Kramers-Kronig Relations, Application to Optical Experiments. Optical Properties of Insulators: Polarization, Ferroelectrics, Berry phase theory of polarization, Optical Modes in Ionic Crystals, Polaritons, Polarons, Experimental Observations of Polarons.

Report-writing on the importance of exciton binding energy for device applications.

Magnetic Properties of Solids [10]
Fundamental Concepts, Diamagnetism and Paramagnetism (Quantum Theory). The Exchange Interaction, Exchange Interaction between Free Electrons, Spontaneous Magnetization and Ferromagnetism. The Band Model of Ferromagnetism. The Temperature Behaviour of a Ferromagnet in the Band Model. Ferromagnetic Coupling for Localized electrons, Ferrimagnetism and Anti ferromagnetism. Spin Waves. Magnetic Resonance Phenomena.

Group discussion on the use of single domain magnetic particle and magnetic resonance in medical field.

Superconductivity [8]
Some fundamental Phenomena Associated with Superconductivity. Phenomenological Description by Means of the London Equation. The BCS Ground State. Consequences of the BCS Theory and Comparison with Experimental Results. Supercurrents and Critical Currents. Quantization of Magnetic Flux. Type-II Superconductors. One-Electron Tunneling in Superconductor Junctions, Cooper Pair Tunneling – The Josephson Effect, and its aplications, SQUID.

Liquid Crystals [6]
Isotropic. Nematic and Cholesteric Phases. Smectics A and –C. Hexatic Phases. Discotic Phases. Lyotropic Liquid Crystals and micro emulsions, MS theory of nematic liquid crystals.

Group discussion and report-writing on the applications of liquid crystals in electronic display.

References:

1. Solid State Physics: David W. Snoke, Pearson Edn.
2. Solid State Physics: N. W. Ashcroft and N. D. Mermin, Saunders College Publishers.
3. Solid-State Physics: H. Ibach and H. Luth, Narosa.

4. Principles of Condensed Matter Physics: P. M. Chaikin and T. C. Lubensky, Cambridge University Press.
5. Introduction to Solid State Physics: C. Kittel, Wiley (2nd Edn.)

PHYS0891: PG Laboratory-III (Computational Techniques)

FORTRAN (or C or C++ or Python) Language [10]
Preparatory courses of writing computer programs

Numerical mathematical analysis [15]
Numerical (mathematical) methods for (i) Basic idea of Interpolation, Lagrange and Newton-Gregory type interpolation (ii) Derivations of the formulae for numerical differentiation (iii) Analysis of errors in different methods (iv) Derivations of the formulae for numerical Integration, Trapezoidal rule, Simpson's rule, Gauss quadrature (v) Analysis of errors (vi) Integration by statistical methods, simple sampling, intelligent sampling (vii) Systematic derivations of the numerical methods of solving ordinary differential equations, Euler method, Its modification, Runge-Kutta method, Taylor's method (viii) Method of solving partial differential equations, solution of Laplace's equation on the lattice, iteration method. (ix) Elementary idea of computer simulation, Monte Carlo techniques, Molecular dynamics, Cellular automata.

Assigned problems in computer laboratory [25]

(i) Interpolation by using difference table and divided difference table

(ii) Derivative by forward difference and central difference method

(iii) Integration by Gauss quadrature method

(iv) Integration by statistical method (simple and intelligent sampling)

(v) Solving ODE by Runge-Kutta and Taylor method

(vi) Solving wave equation and Laplace equation in two dimensions

(vii) Example of Monte Carlo technique

(viii) Example of Molecular dynamics

(ix) Example of cellular automata.

PHYS0892: PG Laboratory-IV

The Following Experiments are part of the lab

1. Determination of the dissociation energy and anharmonicity constant of the iodine molecule by analysing its absorption spectrum.
2. Study of Zeeman pattern of the green line of mercury
3. Calibration of an AF Oscillator.
4. Measuring charge to mass ratio (e/m) of the electron.
5. Construction of sawtooth wave generator and relaxation oscillator and timer circuits, using UJT.

6. Measuring structural parameters of given helical sample using diffraction pattern.
7. Velocity of ultra-sonic waves in a liquid by Debye-Sears effects.
8. Kerr effect.

PHYS0901: Atomic and Molecular Spectroscopy (50 Lectures)

Preliminaries: One electron-atom [4]
Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.

Interaction of radiation with matter [6]
Interaction of an atom with electromagnetic wave: The interaction Hamiltonian, Selection rules; Nonresonant excitation Comparison with the elastically bound electron model; Resonant excitation, Induced absorption and emission.

Fine and Hyperfine structure [10]
Solution of Dirac equation in a central field; Relativistic correction to the energy of one electron atom. Fine structure of spectral lines; Selection rules; Lamb shift. Effect of external magnetic field - Strong, moderate and weak field. Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules.

Many electron atom [8]
Independent particle model; He atom as an example of central field approximation; Central field approximation for many electron atom; Slater determinant; L-S and j-j coupling; Equivalent and nonequivalent electrons; Energy levels and spectra; Spectroscopic terms; Hund's rule; Lande interval rule; Alkali spectra.

Molecular Electronic States [6]
Concept of molecular potential, Born-Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic wave function.

Rotation and Vibration of Molecules [6]
Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

Spectra of Diatomic Molecules [10]
Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules, Continuous spectra, Raman transitions and Raman spectra.

References:

1. *B.H. Bransden and C.J. Joachain*: Physics of Atoms and Molecules
2. *C. Cohen-Tannoudji, B. Dier, and F. Laloe*: Quantum Mechanics vol. 1 and 2
3. *R. Shankar*: Principles of Quantum Mechanics
4. *C.B. Banwell*: Fundamentals of Molecular Spectroscopy
5. *G.M. Barrow*: Molecular Spectroscopy
6. *B.H. Eyring, J. Walter and G.E. Kimball*: Quantum Chemistry
7. *W. Demtroder*: Molecular Physics

8. *H. Herzberg*: Spectra of Diatomic Molecules
9. *J.D. Graybeal*: Molecular Spectroscopy
10. *M.C. Gupta*: Atomic and Molecular Spectroscopy
11. *C. J. Foot*: Atomic Physics (Oxford University Press)

PHYS0902: Classical Electrodynamics (50 lectures)

Basics [16]
Concept of Fields – Scalar, Vector and Tensor fields, Maxwell's equations for electrostatics and magnetostatics: Solutions : role of rotational symmetry; electrostatics - Green's functions, multipole expansions, Boundary value problems, Magnetostatics - Biot-Savart relation, Magnetic moments, Larmor precession, Action principle for test charges in electromagnetic potentials and Lorentz force equation.

Relativistic Formulation of Electrodynamics [14]
Vacuum Maxwell equations for potentials and their symmetries; origin of special relativity and Lorentz invariance; relativistic energy and momentum, relativistic kinematics; relativistically covariant form of Maxwell's equations for potentials: EM waves, propagation in inhomegenous media, transversality and gauge fixing issues; polarization including partial polarization, Stokes parameters, covariant form of Lorentz force equation.

Radiation [20]
Lienard-Wiechert potentials, dipole radiator, radiated power spectrum, multipole radiation; Scattering of electromagnetic waves, Angular distribution of radiation emitted by an accelerated charge; Total power radiated by an accelerated charge; Synchroton radiation, Radiation Reaction of point like charges and fundamental issues of classical electromagnetism.

References:
1. Classical Theory of Electricity and Magnetism: A. K. Raychaudhuri, Springer
2. Introduction to Electrodynamics: Da. J. Griffiths, PHI
3. Classical Theory of Fields: L. D. Landau and E. M. Lifshitz, Pergamon
4. Classical Electrodynamics: J. D. Jackson, Wiley
5. Lectures on Electromagnetism: David Tong, University of Cambridge (Freely available on internet).

PHYS0903A: Advanced Condensed Matter Physics-I (50 Lectures)

Fundamentals of Many-Electron Systems [18]
The Single Particle Approximation of the Many Electron System: Single Product and Determinantal Wave Functions, Matrix Elements of one and two particle Operators. The Hatree-Fock (HF) Theory and the Harftree-Fock approximation of the free electron gas. Single particle levels and the ground state energy. Cohesive energy of metals. The dielectric function of the electron gas, Friedel oscillations. Exchange Interaction and Exchange Hole, Koopmans Theorem. The Occupation Number representation.

The Hubbard model: the U=0 solution, the atomic limit, the case with U > 0, discussion on the symmetries.

The Fermi Liquid theory [12]
Landau Theory of the Fermi Liquid and calculation of equilibrium properties (Specific heat, Compressibility and Spin susceptibility); Effective mass; Transport Properties: First and zero sound. Single particle propagator; spectral representation; Greens function for quasi-particles; Retarded response functions; Density fluctuation excitations and collective modes; Electron Transport: Collision term: relaxation time approximation; Kubo-Greenwood formulation of the transport problem.

Introduction to Renormalization Group (RG) methods [10]
Review of RG in critical phenomena; Renormalization by decimation: Ising spins in one and two dimensional lattices and electronic problems as examples; Stable and unstable fixed points; Kadanoff's block spins, Wilson's RG program.

An introduction to Topology in Condensed Matter [10]
The integer Quantum Hall Effect (a beginner's take); The discovery of Topological Insulators (TI), the basic distinction between a TI and an ordinary insulator; Peierls' instability; Learning topological phase transitions through a toy model: the Su-Schrieffer-Heeger (SSH) Hamiltonian; the edge states; the symmetries – time reversal, chiral, inversion and particle-hole symmetries; the number of edge states as topological invariant; the Zak phase (explicit calculation in an SSH model), and the winding number concept.

References:

1. Advanced Solid State Physics: P. Phillips, Overseas Press
2. Quantum field Theory and Condensed Matter: R. Sankar, Cambridge
3. The Theory of Quantum Liquids: D. Pines and P. Nozieres, W. A. Benjamin
4. The Many Body Problem: Davi Pines, W. A. Benjamin
5. "Teaching the Renormalization Group", H. J. Maris and Leo P. Kadanoff, Am. J. Phys. **46**, 652 (1978)
6. Lecture Notes of Electron Correlation and Magnetism: P. Fazekas, World Scientific
7. A Short Course on Topological Insulators: János K. Asbóth, László Oroszlány, András Pály, Lecture Notes in Physics, 919 (2016)

PHYS903B: Nuclear and Particle Physics-I (50 Lectures)

Symmetries and conservation laws [5]
Noether's theorem, Lorentz and Poincare symmetries, Internal symmetry transformations, Associated conserved charge.

Free Quantum Fields [20]
Klein Gordon field: Free Klein-Gordon equation, Quantum harmonic oscillator and the concept of field quantization, Canonical quantisation, Spectrum, Symmetries and Conservations, Fock space, Feynman propagator.

Dirac field: Dirac equation, anti-commutation relation, canonical quatization spectrum, continuous and discrete symmetries, Fock space, Feynman propagator.

Electromagnetic field: Gauge invariance, gauge fixing, physical state condition, quantization, spectrum, Feynman propagator.

Interacting Quantum Fields [14]
Perturbation Theory, Interaction picture, S-matrix, Wick's Theorem, Examples of interacting field actions, Feynman diagrams, Feynman Rules, Relating S-matrix to cross section.
Coupling of Dirac field with electromagnetic field; Feynman diagrams, Feynman rules for computing amplitudes of elementary processes of QED.

Non-Abelian Gauge Theory [11]
Lie groups, Construction of Lagrangian, Geometry of gauge fields, Spontaneous Symmetry Breaking, Goldstone Bosons, Higgs mechanism.

PHYS0904A: Advanced Condensed Matter Physics-II (50 Lectures)

Fundamentals of transport phenomena in solids [12]

Elementary treatment of magnetoresistance and the Hall effect. The Boltzmann equation formalism and transport in real materials. The relaxation time approximation. Electrical and thermal transport with the linearized Boltzmann equation. Magnetoresistance in two band model.

Electron–phonon interactions [10]

The rigid-ion model. Electron–phonon matrix elements for metals, insulators and semiconductors. Deformation Potential Scattering, Piezoelectric Scattering, Frohlich Scattering. Polarons.

Electronic transitions and optical properties of solids [10]

Response functions. The Drude model for metals. The transverse dielectric function. Interband optical transitions in semiconductors and insulators. Direct and indirect Transitions. Joint Density of States (JDOS). Electron–hole interaction and exciton effects.

Realistic band structure calculations in solids [10]

Numerical Methods: Pseudo potentials and Orthogonalized Planes Waves (OPW), Linear Combination of Atomic Orbitals (LCAO), Plane Waves, Linear Augmented Plane Waves (LAPW).

Magnetotransport [8]

Types of magnetoresistance and mechanisms. Colosal magnetoresistance (CMR). Spin dependent scattering and Giant magnetoresistance (GMR). Valet-Fert model of GMR. Tunnel magnetoresistance (TMR).

References:

1. Charles Kittel, Quantum Theory of Solids, Wiley, Second Revised Printing, 1986.
2. J.M. Jiman, Principles of the Theory of Solids, Cambridge University Press, Second Edition, 1972.
3. David W. Snoke, Solid State Physics: Essential Concepts, Pearson Education, First Edition, 2009.
4. Steven M. Girvin and Kun Yang, Modern Condensed Matter Physics, Cambridge University Press, United Kingdom, 2019.
5. Alberto P. Guimaraes, Principle of Nanomagnetism, Springer, 2009.
6. S.R. Elliott, Physics of Amorphous Materials, Longman, Second Edition, 1990.
7. Charles Kittel, Introduction to Solid State Physics, Wiley, Eighth Edition, 2005.
8. David K. Ferry, Stephen M. Goodnick and J. Bird, Transport in Nanostructures, Cambridge University Press, Second Edition, 2009.

PHYS0904B: Nuclear and Particle Physics-II (50 Lectures)

I. Nuclear Structure:

***Shell Model, Residual Interactions and Multiparticle Configurations* [7]**

Independent Particle model, Two-particle configurations, Residual Interactions; The delta function, Geometrical Interpretation, Pairing Interaction, Multipole Decomposition of residual Interactions. J^π values in Multiparticle Configurations; The m-scheme, Coefficient of fractional Percentage (CFP), Seniority scheme, Pairing correlations, Transition rates.

***Collective Excitations: Vibrational and Rotational Motion* [7]**

Introduction to Collectivity, Configuration mixing, and deformation, Collective Excitations in spherical even-even nuclei, Rotations and Vibrations of axially symmetric deformed nuclei; especially for odd A nuclei, emphasis on particle-rotor coupling, Axially asymmetric nuclei. Development of Collectivity: Phenomenology and Microscopic Basis, Interacting Boson Model and Nuclear Phase transition. Microscopic treatment of collective vibrations: Structure of collective vibrations.

***Deformed Shell Model* [6]**

Nilsson Model and Applications: Examples, Prolate and Oblate Shapes, Interplay of Nilsson Structure and Rotational Motion, Single Nucleon transfer reaction, Coriolis interaction in deformed nuclei, Coriolis mixing and single nucleon transfer cross section, Coriolis effects at higher spins.

***Microscopic theory* [5]**

Occupation number representation, Creation and annihilation operators, One and two-body operators, Matrix elements, Wick's theorem, Hartree-Fock approximation and HF equations. BCS model.

II. Particle Physics:

***Preliminaries* [10]**

Overview of Standard model of particle physics. Symmetries and quarks, SU(3) algebra, Young tableux, Magnetic moment of hadrons.

***Low energy electromagnetic and weak interactions* [15]**

Basic processes in quantum electrodynamics, Mandelstam variables, crossing symmetry, Tree-level cross-section calculations; Fermi's theory of weak interaction, Calculation of decay widths of muon and pions.

References:

1. Nuclear Structure from a simple perspective *by R. F. Casten (Oxford University Press).*

2. Introductory Nuclear Physics *by Kenneth S. Krane (John Wiley & Sons).*

3. Theory of Nuclear Structure *by M. K. Pal (Affiliated East-West Press).*

4. The Nuclear Many-Body Problem *by P. Ring and P. Schuck (Springer Science & Business Media).*

5. Theoretical Nuclear Physics, Vol. I, Nuclear Structure *by DeShalit & Feshbach (J. Wiley, New York).*

6. Introduction to High energy physics by *D. H. Perkins (4th edn. C.U.P. (2000)).*

7. Elementary particles by *D. Griffiths (2nd edn. Wiley, (2008)).*

8. Quarks and Leptons by *F. Halzen, A.D. Martin (Wiley, (1984)).*

9. An Introduction to the Standard Model of Particle physics by *W.D. Cottingham, D.A. Greenwood (2nd edn. C.U.P. (2007)).*

10. Particle physics by *D. Carlsmith, Pearson, (2013).*

11. Gauge theory of elementary particle physics by *Ta-Pei Cheng, Ling-Fong Li (2nd edn. O.U.P. (2000)).*

12. Gauge theories of the strong, weak and electromagnetic interactions by *Chris Quigg (2nd edn. Princeton U.P. (2013)).*

13. Concepts of elementary particle physics by *M. Peskin (O.U.P. (2019)).*

PHYS-0991A: Project-I

Extended Study on any Theoretical or Experimental Subject

PHYS0991B: Quantum Optics and Laser Physics (50 Lectures, Sessional Paper)

Quantization of the free electromagnetic field [4]: Classical field Hamiltonian and the canonical equations of motion, Canonical quantization of the transverse field, Spectrum of the energy-photons, Momentum of the quantized field, Angular momentum of the quantized field, Phase operators for the quantized field, Space-time commutation relations, Vacuum fluctuations, Continuous Fock space, Some theorems on operator algebra.

Coherent states of the electromagnetic field [5]: Fock state representation of the coherent state, The coherent state as a displaced vacuum state-the displacement operator, *q* representation of the coherent state, Time evolution and uncertainty products, Coherent states as a basis; non-orthogonality and over-completeness, Representation of states and operators by entire functions, Diagonal coherent-state representation of the density operator(Glauber-Sudarshan P-representation), The optical equivalence theorem for normally ordered operators, More general phase space representations, Multimode fields, Positive-frequency and negative-frequency field operators, Field produced by a classical current.

Quantum correlations and photon statistics [8]: Photoelectric measurement of the optical field; normal ordering, Photon density operator, Interference experiments; second-order correlation functions, Correlation functions and cross-spectral densities of arbitrary order, Degree and order of coherence, Implications of second-order coherence, Stationarity; homogeneity; isotropy, Anti-normally ordered correlations, Photon statistics, The problem of localizing photons, Effect of an attenuator or beam splitter on the quantum field, Effect of a polarizer on the field, Einstein locality and photon correlations: EPR paradox for an entangled two photon state; Bell's inequality; Clauser-Horne form of Bell's inequality; Experimental confirmation; Non-classical states and Bell inequalities.

Radiation from thermal equilibrium sources [5]: Blackbody radiation: The density operator; Photon statistics; Polarization; Spectral distributions; The diagonal coherent state representation of density operator; Correlation functions of blackbody radiation; Higher-order correlations; Isotropy of Blackbody radiation; Intensity fluctuations of blackbody radiation, Thermal light, Stationary, thermal light beams: Intensity fluctuations of a thermal light beam; Photon statistics with equal average occupation numbers.

Quantum theory of photoelectric detection of light [7]: Interactions of a quantized electromagnetic field, The one-electron photo detection probability, N-electron photo detector, The multiple photoelectric detection probability, The multiple photoelectric detection probability for an arbitrary initial state of the field, Photoelectric correlations: HBT effect; Photocurrent correlations, Bunching and antibunching, Photoelectric counting statistics, Properties of the detection probability p(n,t,t+T).

Interaction between light and a two-level atom [5]: Dynamical variables for a two-level atom: Atomic energy and atomic dipole moment, Bloch representation of the state, Interaction of an atom with a classical field, Interaction between an atom and a quantum field-perturbative treatment; non-perturbative treatment, Resonance fluorescence, Detection of atoms by light, Cooling and trapping of atoms.

Laser Physics [16]: Components of a Laser, Threshold condition, Four-level laser system, CW operation of a laser, Critical pumping rate, Population inversion and photon number in the cavity around threshold, Optical resonators, Cavity modes, Mode selection, Pulsed operation of a laser, Q switching and mode locking. Equation of motion for the density matrix, Laser photon statistics: Linear approximation; Far above threshold; Exact solution, P-representation of the laser, Natural linewidth: Phase diffusion model; Fokker-Plank equation and laser linewidth, Off-diagonal elements and laser linewidth, Analogy between the laser threshold and a second-order phase transition, Solution of the equations for the density matrix elements, An exact solution for the P-representation of the laser. A simple Langevin treatment of the laser linewidth including atomic memory effects, quantum Langevin equations, Photon statistics and laser linewidth.

***Note:** The students are required to submit a dissertation / term paper. The write-up may include results of experiments, literature survey and / or results of any calculation that the student will undertake under the guidance of a course-instructor.*

References:

1. Quantum coherence and quantum optics by Leonard Mandel and Emil Wolf, Cambridge University Press
2. Quantum Optics by Marlan O. Scully and M. Suhail Zubairy, Cambridge University Press
3. Fundamentals of Quantum Optics by John R. Klauder and E.C.G Sudarshan, W.A. Benjamin,Inc.
4. F. Sargeant, M. Scully, W. Lamb, Laser physics (CRC press)
5. K. Thyagarajan, A. Ghatak, Laser physics (Springer)

PHYS0991C: Electronic Materials and Devices (50 Lectures, Sessional Paper)

This sessional paper is comprised of the following components.

- Regular interactive classes on the following topics (total 50 lectures)
- Provision for term paper/ literature review for encouraging research
- Provision for Seminar/ Group discussion/ Assignments as part of continuous evaluation

Materials for Electronic Devices [5]

Brief introduction to single crystal and amorphous semiconductors, thin films and layered structures, grapheme, carbon nanotubes, porous silicon, 2D materials.

Electrical and Optical Processes in Semiconductors [6]
Generation and recombination of electron-hole pairs, Effective mass, Recombination centres, surface states, pinning of Fermi level, carrier transport phenomena, Boltzmann transport equation, Diffusion constant and lifetime of minority carriers, Hayens-Shockley experiment, Thermionic emission, Tunneling process, High field effects.

Semiconductor Junction Devices [6]
Heterojunctions, metal-semiconductor junctions, Schottky diode, negative resistance devices: tunnel diode, IMPATT diode and Gunn diode.

Optoelectronic Materials & Devices [8]
Radiative transitions and optical absorption in semiconductors, light-emitting diodes (LED's), spontaneous and stimulated emission, semiconductor laser: materials, laser operation, basic laser structure, quantum well lasers, photoconductor, photodiode, solar cell, conversion efficiency of p-n junction silicon and compound semiconductor solar cells.

Magnetic Materials and Devices [5]
Ferrimagnetic materials and ferrites, basic concepts of magnetic recording, introduction to spintronics and magnonics.

Fabrication Techniques [8]
Bulk and epitaxial crystal growth techniques, growth of single crystals by Czochralski and Bridgman techniques, purification by float-zone process, epitaxial growth, vapour phase epitaxy, metal-organic chemical vapour deposition, molecular beam epitaxy, thermal diffusion and ion implantation processes for doping, thermal oxidation, dielectric deposition, polysilicon deposition, metallization, lithographic techniques.

Characterization techniques (8)
X-ray diffraction and crystallography, small angle X- ray scattering (SAXS), particle size determination, surface structure, thermal effects on diffraction patterns, Microscopy: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM) and EDAX spectra, Atomic Force Microscopy (AFM), Field Ion Microscopy (FIM), Scanning Tunneling Electron Microscopy (STEM).
Spectroscopy: Infrared and Raman spectroscopy, Photoluminescence, Photoemission and X-ray spectroscopy. Magnetic Resonance

Applicability/Extended Studies [4]
Multijunction, heterojunction and thin film solar cells, novel materials. Critical thinking on temperature dependence of mobility, negative differential mobility, microwave applications of the devices.

References

1. S. M. Sze and M. K. Lee, Semiconductor Devices: Physics and Technology, 3rd Ed., John Wiley & Sons, Inc. USA, 2012.

2. D. K. Schroder, Semiconductor Material and Device Characterization, 3rd ed., John Wiley & Sons, Inc., Hoboken, New Jersey and Canada, 2006.
3. W. D. Callister, Jr. and D. G. Rethwisch, Fundamentals of Materials Science and Engineering: An Integrated Approach, 5th Ed., John Wiley & Sons, Inc., USA, 2015.
4. S. O. Kasap, Principles of Electronic Materials and Devices, 4th Ed., McGraw-Hill Education, New York, 2018.

PHYS1001A: Advanced Condensed Matter Physics-III (50 Lectures)

Spin and Magnetic Systems [10]
Overview of magnetic properties. The Ising model: zero external magnetic field; Spontaneous symmetry breaking, External magnetic field, Hysteresis. Critical fluctuations: other magnetic models, Multi critical behaviour, Metamagnets, Critical Exponents and Magnetic Susceptibility, Landau Coarse Graining Theory. Spin Waves and Goldstone Bosons, Mermin-Wagner theorem. Spin-Spin Interactions: Ferromagnetic instability, Localized states and RKKY Exchange Interactions.

Physics of continuous symmetric spin models [10]
Concept of continuous symmetry, XY-Model, Exact solution in one dimensions, Behaviour of specific heat, XY-model in two dimensions, Absence of long range ferromagnetic order, Vortices and antivortices, Heisenberg model, Heisenberg ferromagnet, Heisenberg metamagnet.

Quantum magnetic models and phase transition [15]
Concept of quantum magnetic models, Transverse Ising model, Phase transition, Valence bond states, Majumder-Ghosh chain for spin systems, Ground state, Holstein-Primakoff transformation, Mapping of Spin- models to Bosonic model, Spin-1/2 XY model, Jordan-Wigner transformation, Mapping of spin model to spinless fermionic model, Band structures, Quantum phase transitions.

Superconductivity [15]
Constructing Bosons from Fermions. Electron Electron Interaction via Lattice, Cooper Pairs, BCS Wave function. Bogoliubov-de Gennes equations, Excitation Spectrum of a Superconductor. Ginzburg Landau Theory. Type II Superconductors, Characteristics Length. Novel High-Temperature Superconductors.

References:
1. Quantum phase transition- Subir Sachdev - Cambridge University press-2012
2. Quantum Ising phases and transitions in transverse Ising models- B. K. Chakrabarti, A. Dutta, P. Sen - Springer-1996
3. Introduction to superconductivity- M. Tinkham - McGraw Hill (NewYork)-2009

PHYS1001B: Nuclear and Particle Physics-III (50 Lectures)

I. Nuclear Reactions:

***Survey of reactions of nuclei* [4]**

Strong, electromagnetic and weak processes, Types of reactions and Q-values, Reaction mechanisms: Energy and time scales for direct and compound reactions, Experimental observables: Cross-sections - definitions and units; Angular distributions, Excitation functions.

***Direct reactions* [14]**

From Hamiltonian to cross sections for elastic scattering; S-matrix and its symmetry and reciprocity; optical potential, Green functions methods: T-matrix expression, two potential formula, plane-wave and distorted-wave Born series, basic principles of coupled-channel method.

Reference to folded potential, nuclear density, inelastic excitation, electric B(Ek) and nuclear deformations, transfer reactions, spectroscopic factors, connection with nuclear structure, asymptotic normalization constant (ANC), R-matrix approach for direct reaction.

***Compound nuclear reactions* [4]**

Statistical model and Weisskopf-Ewing formula.

R-matrix methods: Dispersion theory.

***Nuclear reactions with radioactive ion beam* (*RIB*) [3]**

Production of radioactive ion beam (RIB), Neutron rich nuclei and nuclei beyond the drip line.

II. Particle Physics

***Hadronic physics* [15]**

Elastic electron-proton scattering, Electromagnetic form factors, Deep-inelastic lepton-hadron scattering, Structure functions, Scaling and its violations, Quantum chromodynamics. Flavour physics, Cabibbo Kobayashi-Masakawa matrix, Oscillations and CP violation in the K and B systems.

***Electroweak physics* [10]**

Electroweak sector of the Standard model, Gauge boson and fermion masses, Calculation of tree-level decay widths of W, Z and Higgs boson, Limitations of the Standard model.

References:

1. Introduction to Nuclear Reactions *by G. R. Satchler (Oxford University Press).*
2. Nuclear Reaction and Nuclear Structure *by P. E. Hodgson (Clarendon Press).*
3. Heavy Ion reactions, Vol. I & II *by R. A. Broglia & Aage Winther (Benjamin/Cummings).*
4. Techniques for Nuclear and Particle Physics Experiments *by W. R. Leo (Springer Science & Business Media).*
5. Nuclear Physics, Principles and Applications *by J. S. Lilly (John Wiley & Sons).*
6. Introduction to High energy physics by *D. H. Perkins (4th edn. C.U.P. (2000)).*
7. Elementary particles by *D. Griffiths (2nd edn. Wiley, (2008)).*

8. Quarks and Leptons by *F. Halzen, A.D. Martin (Wiley, (1984)).*

9. An Introduction to the Standard Model of Particle physics by *W.D. Cottingham, D.A. Greenwood (2nd edn. C.U.P. (2007)).*

10. Collider physics by *Vernon D. Barger, Roger J.N. Phillips (Updated edn. Addison Wesley, (1997)).*

11. Particle physics by *D. Carlsmith, Pearson, (2013).*

12. Gauge theory of elementary particle physics by *Ta-Pei Cheng, Ling-Fong Li (2nd edn. O.U.P. (2000)).*

13. Gauge theories of the strong, weak and electromagnetic interactions by *Chris Quigg (2nd edn. Princeton U.P. (2013)).*

14. Concepts of elementary particle physics by *M. Peskin (O.U.P. (2019)).*

PHYS1002A: Advanced Condensed Matter Physics-IV (50 Lectures)

Dynamics of electrons in a magnetic field [12]

Two Dimensional Electron Gas. Landau levels and quasiparticles in a magnetic field. Density of states in Landau levels. Quantum oscillations: periodicity in $1/B$ and the de Haas–van Alphen effect in metals. Shubnikov De Hass Oscillations. Integer Quantum Hall Effect (IQHE), Fractional Quantum Hall Effect (FQHE) and higher order quasiparticles.

Non-crystalline materials [13]

Noncrystalline and glassy materials: Preparation, Structure, and X-ray diffraction pattern of amorphous materials, Radial distribution function (RDF). Glasses, glass transition temperature, tunnelling states, specific heat estimation, two-level systems. Amorphous semiconductors: electrical and optical properties. Magnetic properties, switching and device applications.

Low-dimensional systems and nano-scale physics [15]

Density of states and optical properties. Ballistic transport and quantization of conductance. Quantum confinement effect, quantized energy levels of quantum dots and quantum wires. Quantum Wells: Fabrication, Lattice Matching, Electron States, Exciton and Donors in Quantum Wells, Graphene: Structure, Electron Energy Bands, Eigenvectors, Landau Levels, Electron-Phonon Interaction, Carbon Nanotubes: Chirality, Electronic States, Phonon in Carbon Nanotubes, Electrical Resistivity. Other quasi-2D materials.

Topological Quantum Matter [10]

Spin-1/2 Berry phase: spin-orbit coupling and suppression of weak localization. Haldane model. Thouless charge pump and electric polarization: modern theory of electric polarization. The Kane-Mele Model. Z_2 Characterization of Topological Insulators. Massless Dirac Surface/Interface States. Weyl Semimetals. Fermi Arcs on the Surface. Chiral Anomaly.

References:

1. Charles Kittel, Quantum Theory of Solids, Wiley, Second Revised Printing, 1986
2. J.M. Jiman, Principles of the Theory of Solids, Cambridge University Press, Second Edition, 1972.

3. David W. Snoke, Solid State Physics: Essential Concepts, Pearson Education, First Edition, 2009.
4. Steven M. Girvin and Kun Yang, Modern Condensed Matter Physics, Cambridge University Press, United Kingdom, 2019.
5. Alberto P. Guimaraes, Principle of Nanomagnetism, Springer, 2009.
6. S.R. Elliott, Physics of Amorphous Materials, Longman, Second Edition, 1990.
7. Charles Kittel, Introduction to Solid State Physics, Wiley, Eighth Edition, 2005.
8. David K. Ferry, Stephen M. Goodnick and J. Bird, Transport in Nanostructures, Cambridge University Press, Second Edition, 2009.
9. Topology in Condensed Matter :**An Introduction,** M. Araujo and P. Sacramento, World Scientific, https://doi.org/10.1142/12286 | May 2021
10. Weyl Semimetals: a short review – Sumathi Rao, https://arxiv.org/abs/1603.02821
11. Annual Review of Condensed Matter Physics - Weyl Metals, A.A. Burkov, https://www.physics.rutgers.edu/grad/601/CM2018/weyl2.pdf

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PHYS1002B: Nuclear and Particle Physics-IV (50 Lectures)

I. Nuclear Reactor Physics: [16]

Nuclear Fission and Fusion processes and Neutron Interaction: Nuclear Fission and Fusion, Neutron Interactions and Energy distributions, Neutron Scattering, Energy-Averaged Reaction Rates, Infinite medium multiplication.

Power Reactor Core and Reactor Kinematics:
Core Composition, Fast reactor lattices, Thermal Reactor Lattices; The four factor formula and Pressurized water reactor example; Neutron Balance equations, Multiplying Systems Behaviour, Delayed Neutron Kinematics, Step Reactivity Changes.

Neutron Distributions and Spatial Diffusion:
Neutron Diffusion equation, Nonmultiplying Systems – Plane and Spherical Geometry, Boundary Conditions, Multiplying Systems, Uniform reactors, Neutron Leakage, Reflected Reactors, Control Poisons.

Energy Transport, Reactivity Feedback and Long-term Core behaviour
Core power distribution, Heat Transport, Thermal Transients; Reactivity Coefficients, Composite coefficients, Excess Reactivity and Shutdown Margin, Reactor Transients, Reactivity Control, Fuel Depletion, Fission Product and Actinide Inventories.

II. Accelerator Physics [17]

Overview over different types of accelerators: Circular and linear, collider, cooler rings, synchrotron light-sources, medical accelerators, cyclotrons.

Transverse and longitudinal beam dynamics: matrix methods, emittance, beta functions, dispersion phase-stability. Limitations due to space charge and instabilities. Technical components such as magnets, radio-frequency systems, vacuum, particle sources and diagnostic for current, position and beam size.

III. Physics of Nuclear and Particle Detectors [17]

General Properties of Radiation Detectors:
Simplified Detector Model, Modes of Detector Operation, Pulse Height Spectra, Counting Curves and Plateaus, Energy Resolution, Detection Efficiency, Dead time; Ionization Chambers, Proportional Counters, Geiger-Mueller Counters.

Scintillation and Semiconductor Diode Detectors:
Organic and Inorganic Scintillators, Light Collection and Scintillator Mounting; Photomultiplier Tubes and Photodiodes, Radiation Spectroscopy with Scintillators.

Action of Ionizing Radiation in Semiconductors, Semiconductors Detector Configurations, Operational Characteristics, Applications of Silicon and Germanium Diode Detectors; Gamma Ray Spectroscopy with Germanium Detectors; Lithium-Drifted Silicon Detectors, Photoconductive Detectors, Position-Sensitive Semiconductor Detectors.

Particle Identification and Spectroscopy:
Nuclear Reactions of Interest in Neutron Detection, Detectors Based on Boron Recation; Counters based on Neutron Moderation, Detectors based on Fast Neutron-Induced Reactions; Time-of-flight measurement, Cherenkov counters; measurement of energy: Hadron calorimeters; measurement of momentum and time.

Applications of detector systems:
Detector systems for Medical applications, ion-atom collisions, heavy-ion reactions, high-energy experiments, hadronic reactions

References:

1. Nuclear Reactor Engineering Vol. 1: Reactor Design Basics *by Glasstone & Sesonake.*
2. Nuclear Reactor Theory *by Bell and Glasstone*.
3. Fundamentals of Nuclear Reactor Physics *by E. E. Lewis (Academic Press).*
4. Particle Accelerator Physics *by H. Wiedemann (Springer).*
5. Accelerator Physics *by S. Y. Lee (World Scientific).*
6. Radiation Detection and Measurement *by G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.).*
7. The physics of particle detectors *by Dan Green (Cambridge University Press)*
8. Detectors for Particle radiation *by Konrad Kleinknecht (Cambridge University Press)*

PHYS1091A: Condensed Matter Physics-V Laboratory

The Following Experiments are part of the lab

1. Determination of Space Group and Crystal Structure of a Single Crystal Material by Laue Diffraction Method.
2. Determination of Crystal Structure and Lattice Parameters of a Polycrystalline Material by Powder Diffraction (Debye Scherrer) Method.
3. Determination of Hall Effect &Magnetoresistance of Polycrystalline Bismuth Sample at RT.
4. Determination of Magnetic Susceptibility of Paramagnetic Salts by Guoy Balance Method.
5. Determination of AC Conductivity and Dielectric Constants of Composites Materials by LCR Bridge.
6. Study of Dielectric Constants of Ferroelectric Crystals at Elevated Temperatures and determine the Curie Temperature.
7. Study of F Centers of Xray Irradiated Alkali Halides (KCl&KBr) Samples.
8. Study of the Nature of Band Gap and Determination of Optical Constants (n, k) of Semiconductor (Crystalline and Amorphous) Thin Films using UV-VIS (Dual and Single beam) Spectrophotometer.
9. FTIR Study of Si Based Oxide/ Carbon Nano Composites.
10. Study of the variation of Hall Coefficient of a given extrinsic semiconductor as a function of temperature using Temperature dependence Hall-effect setup.
11. Study of the electrical properties of given thin films of different materials (metal, insulator and semiconductor) using Four-Probe Setup.
12. Measurement of electrical resistivity of superconductors at low temperature.

(Students will do 6-8 experiments among these)

PHYS1091B: Nuclear and Particle Physics-V Laboratory

Any four of the experiments listed in 3-12 will be performed

1. Interactive tutorial on perturbative quantum electrodynamics (QED), including regularization of divergent amplitudes in QED.
2. Interactive tutorial on renormalization of electron charge and mass in QED.
3. a) Determination of the Plateau region of a GM tube.
    b) Analysis of statistical fluctuations at low and high count rates.
4. Verification of inverse square law for γ-rays using a GM tube.
5. Estimation of efficiency of the G. M. detector for (a) Gamma source and (b) beta source.
6. Determination of the half-life of a long lived radioactive sample (^{40}K).
7. Study of beta and gamma absorptions in low and high Z materials (Al, Cu and Pb) using a GM tube and determination of range and energy of beta particles.

8. Study of alpha scattering from metal targets and verification of the Rutherford formula and identification of the target element.
9. Beta-gamma coincidence measurements: study of decay schemes and lifetime of nuclear levels.
10. Gamma-gamma coincidence measurements: angular correlation of the two positron annihilation gammas from ^{22}Na source.
11. Energy distribution and Energy Loss Measurements of the Fission Fragments from ^{252}Cf source.
12. Measurement of the thickness of a thin foil from alpha energy loss.

References:

1. Introductory Nuclear Physics *by Kenneth S. Krane (John Wiley & Sons).*
2. Radiation Detection and Measurement *by G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.).*
3. Nuclear Physics, Principles and Applications *by J. S. Lilly (John Wiley & Sons, Inc.).*
4. Techniques for Nuclear and Particle Physics Experiments *by W. R. Leo (Springer Science & Business Media).*

PHYS1092: Grand Viva

(An overalltest of the conceptual knowledge of physics)

PHYS1093A: Project-II (continuation of Project-I)

PHYS1093B: Physics of Nanostructured Materials
(50 Lectures, Sessional Paper)

Introduction to Nanostructured Materials [8]
Introduction. Size dependence of properties. Metal nanoclusters, bulk to nano transition, semiconducting nanoparticles. Carbon nanostructures: carbon clusters, carbon nanotubes (CNT), fullerenes and graphenes, nanocomposites and hybrids

Growth, fabrication and measurement techniques for nanostructures [12]
Spontaneous formation and ordering of nanostructures. Top-down and bottom-up approach and templates. Methods of synthesis of nanostructures: RF plasma, chemical methods, Sol-Gel technique, electrochemical methods, thermolysis, pulsed laser methods, Physical vapor deposition, ball milling, vapour-liquid-solid (VLS) method. Methods of carbon nanotube growth. Nanostructures determination: atomic structures, X-ray diffraction and crystallography, small angle X- ray scattering (SAXS), particle size determination, surface structure. Microscopy: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Field Ion Microscopy (FIM), Scanning Tunnelling Electron Microscopy (STEM). Spectroscopy: Infrared and Raman spectroscopy, Photoluminescence, Photoemission

and X-ray spectroscopy. Magnetic Resonance

Electron transport in Semiconductors and Nanostructures [14]
Time and length scales of electrons in solids. Statistics of electrons in solids and nanostructures. The density of states (DOS) of electrons in nanostructures. Electron transport in nanostructures: dissipative transport in short structures, hot electrons, quantum ballistic transport and Landauer formula, single electron transport. Electrons in traditional low-dimentional structures (quantum wells, quantum wires & quantum dots).

Nanostructured Ferromagnetism [6]
Magnetic properties of nanostructured materials. Dynamics of nanomagnets. Dilute magnetic semiconductor (DMS), Spintronics. Nanocarbon ferromagnets. Ferrofluids. Super paramagnetism. Ferromagnetic resonance (FMR).

Self-assembly and Catalysis [4]
Self-assembly: process of self-assembly, semiconductor islands, monolayers. Catalysis: nature of catalysis, surface area of nanoparticles, porous materials, pillared clays and colloids.

Applications and Future of Nanomaterials [6]
Nanoelectronics: single electron transistor, resonant tunnelling diodes. Micro and nanoelectro mechanical systems. Nanosensors. Nanocatalysis. Role of nanomaterials in food and agriculture industry & water treatment. Nano-medical applications. Defence and space applications. Nanomaterials for non-conventional energy source and energy storage.

PHYS1093C: General Theory of Relativity
(50 lectures, Sessional Paper]

Introduction [5]
Newtonian gravity; Inertial frames; Gravitational and inertial mass; Space, time and gravity in Newtonian physics; Revisit special relativity and flat spacetime; Scope of General relativity.

Geometry as Physics [12]
The priciples of general relativity; Gravity as geometry; Coordinates and line element; Geodesics; The variational method for geodesics, isometries – Killing vectors and conserved quantities; solution of geodesic equation. Riemannian geometry: Elementary operations with tensors, Derivative of a tensor, Riemannian affine connection, Parallel transport, Riemann tensor, Geodesic deviation, Ricci tensor, Ricci scalar, Einstein tensor.

Theory of Gravitation: Einstein Field Equation [8]
Einstein-Hilbert action; Derivation of Einstein equation from action principle; The matter energy momentum tensor and Cosmological Constant; Einstein equation for weak gravitational fields; Newtonian limit.

Schwarzschild Geometry, Gravitational Collapse and Blackhole [10]
Static spherically symmetric spacetime, Birkhoff's theorem, Properties of Schwarzschild metric, Weak field limit; Particle and photon orbits, anomalous precession of perihelia, bending of light; Approaching and crossing the Schwarzschild radius – infinite gravitational red shift, vertical free fall, black hole, event horizon.

Linearized Gravity and Gravitational Radiation [7]
The linearized Einstein equation; Gauge freedom and coordinate choices; The wave equation; Polarization; Physical effects of gravitational waves; Sources of gravitational radiation – quadrupole formula for the energy loss; Detection of gravitational waves;

Maximally Symmetric Spaces [8]
Homogeneous, isotropic and maximally symmetric spaces, Embeddings, n-sphere and anti de Sitter metric. Matter content as perfect fluid; Conservation laws; The Einstein and Friedman equations; Exact solutions; The dynamics and observation of FRW universe; Limitations and modern perspectives.

The sessional paper includes (i) regular interactive lecture periods on the above mentioned topics, (ii) assignments / discussions / class tests as part of continuous evaluation, (iii) provision for term paper on foundational and modern aspects of gravitational physics, (iv) provision for seminar / write up on the topic of term paper.

References:

1. Gravity, James B. Hartle, Addison Wesley (2003)
2. Spacetime and Geometry, Sean M Carroll, Addison Wesley (2004)
3. A First Course in General Relativity, Bernard F. Schutz, CUP (2004)
4. Introducing Einstein's Relativity, Ray D'Inverno, OUP (1998)
5. General Relativity, Norbert Straumann, Springer (2013)
6. General Relativity, M. P. Hobson, G. P. Efstathiou, A. N. Lasenby, CUP (2006)

PHYS1093D: Nonlinear Physics (50 Lectures, Sessional Paper)

Nonlinear Waves [12]
Solitons, Korteweg-de Vries (KdV) equation and other nonlinear equations, Important soltution techniques, Symmetries.

Nonlinear Dynamics of Autonomous Systems [25]
General overview dynamical systems, One dimensional phase space, Flows, Fixed points and Stability, Classification of bifurcations – perfect and imperfect, Relation with phase transition and critical phenomena. Applications in biological systems, Synchronization.
Two-dimensional phase space and phase portrait, Classification of Fixed points and Bifurcations in two-dimensions, Limit cycles, Closed orbits, Poincare-Bendixon theorem, Forced non-linear oscillators – van der Pol, Duffing. Numerical simulation of the trajectories.

Nonlinear dynamics of Discrete Systems [13]
One-dimensional maps, Logistic map, period doubling, Lyapunov exponent, Lorenz map, Strange attractor, Chaos, Feigenbaum's theory, Interdisciplinary applications of non-linear dynamics.

Note: *The students are required to submit a dissertation / term paper. The write-up may include results of experiments, literature survey and / or results of any calculation that the student will undertake under the guidance of a course-instructor.*