Department of Physics
Indian Institute of Engineering Science and Technology, Shibpur

Two-year M.Sc. in Physics

Course Structure

First Semester

Sl. No.	Subject Type	Subject Code	Subject Name	Class Load/Week			Total load/ Week	Credit	Marks
				L	T	P			
1	Core	PH5101	Mathematical Methods of Physics	3	1	0	4	4	100
2	Core	PH5102	Classical Mechanics	3	1	0	4	4	100
3	Core	PH5103	Quantum Mechanics-I	3	1	0	4	4	100
4	Departmental Elective	PH5121	Gravitation and Astrophysics	3	0	0	3	3	100
		PH5122	Interaction of Radiation with Matters: Detection of Charged and Neutral Particles.						
		PH5123	Physics of Semiconductor Devices.						
		PH5124	LASER, Fibre Optics and their Applications						
5	Open Elective	PH5161	Dynamical Systems-I	3	0	0	3	3	100
		PH5162	Basics and Applications of Quantum Mechanics.						
6	Laboratory	PH5171	General Physics Laboratory	0	0	6	6	3	100
7	Laboratory	PH5172	Computer Programming and Computational Techniques.	0	0	3	3	2	50
Total				**15**	**3**	**09**	**27**	**23**	**650**

Second Semester

Sl. No.	Subject Type	Subject Code	Subject Name	Class Load/Week L	T	P	Total load/ Week	Credit	Marks
1	Core	PH5201	Electromagnetic Theory	3	1	0	4	4	100
2	Core	PH5202	Electronic Devices and Circuits	3	1	0	4	4	100
3	Core	PH5203	:Quantum Mechanics-II	3	1	0	4	4	100
4	Departmental Elective	PH5221	Advanced Optics	3	0	0	3	3	100
		PH5222	Computational Physics						
		PH5224	Plasma Physics						
5	Open Elective	PH5261	Principle of Detectors and Data Acquisition Systems for Radiation Detection	3	0	0	3	3	100
		PH5262	Physics and Applications of Quantum Structures						
6	Laboratory	PH5271	Basic Electronic Circuit Laboratory	0	0	6	6	2	100
7	Thesis/Project	PH5291	Term Paper	0	0	8	8	4	100
8	Thesis/Project/ Viva	PH5292	Term Paper Viva					2	50
Total				**15**	**3**	**14**	**32**	**26**	**750**

Third Semester

Sl. No.	Subject Type	Subject Code	Subject Name	Class Load/Week L	T	P	Total load/ Week	Credit	Marks
1	Core	PH6301	Atomic and Molecular Physics	3	1	0	4	4	100
2	Core	PH6302	Nuclear Physics	3	1	0	4	4	100
3	Core	PH6303	Solid State Physics	3	1	0	4	4	100
6	Laboratory	PH6371	Advanced Laboratory	0	0	6	6	3	100
7	Thesis/Project Report	PH6391	M.Sc. Thesis Part-I	0	0	16	16	8	100
8	Thesis/Project Viva	PH6392	Seminar and Viva of M.Sc. Thesis Part-I	0	0	0	0	2	100
Total				**9**	**3**	**22**	**34**	**25**	**600**

Fourth Semester

Sl. No.	Subject Type	Subject Code	Subject Name	Class Load/Week L	T	P	Total load/ Week	Credit	Marks
1	Core	PH6401	Statistical Mechanics	3	1	0	4	4	100
2	Departmental Elective	PH6421	Physics of Materials	3	0	0	3	3	100
		PH6422	Nuclear Physics and Nuclear Astrophysics						
		PH6423	Field Theory and Particle Physics						
		PH6424	Advanced Condensed Matter Physics						
3	Laboratory	PH6471	Special Laboratory for Condensed Matter Physics	0	0	6	6	3	100
		PH6472	Special Laboratory for Nuclear and Particle Physics						
4	Thesis/Project Report	PH6491	M.Sc. Thesis Part-II	0	0	16	16	8	200
5	Thesis/Project Viva	PH5292	Seminar and Viva of M.Sc. Thesis Part-II	0	0	0	0	4	100
Total				**6**	**1**	**22**	**29**	**22**	**600**

Total Credits = 23+26+25+22=96

Total Marks = 650 + 750 + 600 + 600 = 2600

Note: The Subject Code is WWXYZZ, where
WW: Department Code (e.g., CH, PH, MA, GE, etc.);
X: Year (1, 2, 3, 4 for B. Tech; 5, 6 for M. Tech, MSc., MBA; 8 for PhD.)
(1, 2, 3, 4, 5 for BArch.; 6, 7 for MPlan)
Y: Sem. Code - 1 for odd semester and 2 for even semester
ZZ: 01-20- for Core Courses
21-60-for Dept. Electives
61-70-for Open Electives
71-90- for Laboratory Courses with weekly class load
91-99-for Thesis/Project/Internship/Viva, etc. without weekly class load

Mathematical Methods of Physics

Core Course (Credit=4)

PH5101

Full Marks: 100 **(3L+1T)/Week**

Complex Variable: Analytic functions, cauchy-Riemann equation; Cauchy's integral formula; Taylor's expansion, Laurent's expansion; singularities and zeros; Residue formula and its application for evaluation of integrals.

Differential Equations: The hyper geometric equation and functions; Confluent hyper geometric equation and functions; Representation of Legendre, Bessel and Hermite functions in terms of hyper geometric functions. Properties of Legendre, Bessel, Hermite and Laguerre functions.

Transform theory: Laplace transformation and inverse Laplace transformation; Applications of Laplace transformation; Fourier integral transform of a finite wave group; convolution theorem. Use of Fourier transformation in solving differential equations.

Elementary Probability Theory, random variables, binomial, Poisson, and normal distributions, central limit theorem.

Definition of groups, multiplication table, conjugate elements and classes, subgroups; direct product of groups; isomorphism & homomorphism, Permutation groups. Group representations, Schur's Lemma, Orthogonality theorem, Character table, Continuous group and discussion on SU(2) and O(3).

Linear space and operators: Vector space, inner product space, Schmidt's orthogonalisation method, Schwartz inequality. Linear operators- matrix representation of operators. Special operators-conjugate operators, adjoint and self adjoint operators, unitary operators, othogonality.

Tensors: General definition, contravariant, covariant and mixed tensors and their ranks. Outer product of tensors, contraction of tensors, inner product of tensors. Symmetric and antisymmetric tensors; Kronecker delta. Metric tensor, raising and lowering of indices; Cartesian tensors.

References:

i) "Mathematical methods for physicists", G. B. Arfken, H. J. Weber and F. E. Harris.
ii) "Complex variables: Introduction and Applications", M. J. Ablowitz and S. Fokas
iii) "Complex variables and applications", J. W. Brown and R. V. Churchill.
iv) "Mathematics for Physicists", P. Dennry and A. Krzywicky.
v) "Schaum's outline of Linear Algebra", S. Lipschutz and M. Lipson.
vi) "Group Theory and Quantum Mechanics", Michael Tinkham.
vii) "Calculus: Multi-Variable Calculus and Linear Algebra with Applications to Differential Equations and Probability", Vol 2, T. M. Apostol

Classical Mechanics

Core Course (Credit=4)

PH5102

Full Marks: 100 **(3L + 1T)/Week**

Pre requisite: Basic Knowledge about Generalized coordinates, Lagrangian Mechanics, Hamilton's equation, Angular momentum, Rigid body dynamics, small oscillations in one and two degrees of freedom. Special theory of relativity, mass energy equivalence.

Unit1: Hamiltonian Formulation: Recapitulations on Principle of least action and Hamilton's principle, Poisson's bracket and canonical transformation, Hamilton Jacobi Theory, separation of variables, cyclic coordinates, Conservation laws and Noethers theorem, Action angle variables application to harmonic oscillator and Kepler problem.

Unit2: Rigid body dynamics: Finite and infinitesimal rotation, Euler's theorem, principal axis transformation, Euler angles, Heavy symmetric top with and without friction.

Unit3: Oscillations in higher degrees of freedom: Condition of stability, equilibrium, similarity transformation, normal coordinates and normal modes, Vibration of molecules under Born-Openheimer approximation, Forced vibration of system of particles and effect of dissipative forces. Beyond small oscillation- anharmonic oscillator, parametric resonance, Introduction to classical chaos.

Unit4:Relativistic Mechanics: Minkowski space, Lagrangian and Hamiltonian of relativistic particles, decay and collision problem, two body collision and Mandelstam variables**.**

References:

1. "Classical mechanics", H. Goldstein, C P. Poole – 3rd Ed
2. "Mechanics: Courses on Theoretical Physics" Vol. -1, L.D. Landau and E M Lifshitz
3. "The Classical theory of fields: Courses on Theoretical Physics" Vol. -2, L.D. Landau and E M Lifshitz
4. "Classical Mechanics", N.C. Rana and P.S. Joag
5. "Introduction to classical mechanics", R.G. Takwale and P.S. Puranik
6. "Relativistic Kinematics; A Guide To The Kinematic Problems in High Energy Physics", R. Hagedron, (Addison Wesley Longman, 1973).

Quantum Mechanics– I

Core Course (Credit=4)

PH5103

Full Marks: 100 **(3L+1 T)/Week**

A. Dirac delta function and Fourier transformation - de Broglie wave - Gaussian wave packet- meaning of spreading with time - obtaining Schrödinger equation - observables as operators - general form of solution of Schrödinger equation - wave packet (Linear superposition) - interpretation of the wave function - summarise the postulates of wave mechanics.

B. Stern - Gerlach experiments - Complex vector space - basic mechanics of vector space as used in quantum mechanics - Ket space and Bra - space and fundamental postulates - inner product , positive definite metric - normalised ket - operators - Hermitian adjoint - Multiplication of operators - The associative axioms - Hermitian operator.

C. Base Kets and matrix representation - eigen kets of an observable - orthonormal set as base kets - Completeness relation - matrix representation of operator and state ket and bra - measurements, observables - Collapse of the wave function - expectation value - Compatible and incompatible observables - maximal set of commuting observables - Selective measurements - change of basis - diagonalisation - Unitary equivalent observables.

D. Continuous spectra - position eigenkets and position measurements - expansion of an arbitrary ket in position basis and the meaning of the expansion coefficient - Space Translation operator and its properties - derivation of $[x_i, p_j] = (ih/(2\pi))\,\delta_{ij}$ - relation between classical and quantum brackets - Jacobi identity - wave function in position and momentum space.

E. Quantum dynamics - time evolution operator and its properties - obtaining Schrödinger equation - explicit forms of time - evolution operator - time evolution of energy eigenkets - time - dependent of expectation values - spin precession - Schrödinger and Heisenberg pictures - Heisenberg equation of motion - Ehrenfest's Theorem - Base kets and transition amplitudes.

F. Theory of angular momentum - infinitesimal and finite rotation operators in Quantum Mechanics - Rotation Group - fundamental commutation relations of angular momentum - finite rotations: spin 1/2 system - Pauli two - component formalism - O(3), SU(2) - Euler rotation in Quantum Mechanics - D - matrix.

G. Angular momentum using operator approach - Raising and Lowering operators - Matrix representations for angular momentum operators - Addition of two angular momenta - Clebsch-Gordan coefficients and their calculations.

H. Linear harmonic oscillator using operator technique - annihilation, creation and number operators and their matrix representations - Charged particle in a magnetic field problem by operator technique - Landau levels - Coherent states and their properties.

I. Time-independent (Rayleigh-Schrödinger) perturbation theory for non-degenerate cases -Applications to perturbed linear harmonic oscillators, perturbed square-well potentials and He-atom ground state.

J. Time-independent perturbation theory for degenerate cases - Removal of degeneracy - Linear Stark effect in n=2 state of H-atom - Two-dimensional isotropic oscillator problem.

References:

i) “Quantum Physics “, S. Gasiorowicz.
ii) “Modern Quantum Mechanics”, J. J. Sakurai.
iii) “Quantum Mechanics”, K. T. Hecht.
iv) “Quantum Mechanics”, B. H. Bransden and C. J. Joachain.
v) “Quantum Mechanics”, L. I. Schiff.

Gravitation and Astrophysics

Departmental Elective (Credit=3)

PH5121

Full Marks: 100 **3L/ Week**

Introduction to gravitation and astrophysics: Newtonian cosmology and astrophysics. Tensor algebra and calculus, metric, metric tensor, gradient, curl, divergence, tensor densities, covariant derivative, Christoffel symbol, Parallel transport, geodesics, Riemann tensor, Uniqueness of curvature tensor, Ricci tensor, Bianchi identities, geodesic deviation, Energy-momentum tensor.

General theory of relativity: The principle of equivalence and its consequences-Einstein's field equation, the cosmological constant. The Schwarzschild solution, singularity, horizon, black hole, Penrose process, Hawking radiation (qualitative), application to solar system, red shift, perihelion precession of Mercury .

The RW metric: Cosmological Principle, observational cosmology, high red shift objects (QSOs), event horizon.

Origin of anisotropy. Galaxy formation (qualitative). Origin of the concept of dark matter and dark energy.

Gravitational Radiation: Weak field approximation- plane waves, energy and momentum of plane waves, generation and detection of gravitational waves GW1708 (qualitative description).

Stellar equilibrium and collapse: Differential equations of stellar structure - isotropic stars and interior metric - role of central density. Stellar evolution equations and boundary condition for Sun. Newtonian stars - polytropes, white dwarfs - chandrasekhar's limit. Openheimer-Volkoff limit, Neutron stars. Super massive stars (qualitative).

Interior solution in co-moving coordinates, collapse time, inevitability of collapse, black holes.

References:

i) "Introduction to General Relativity", R. Adler, M. Bazin and M. Schiffer.
ii) "General Relativity and Cosmology", J. V. Narlikar.
iii) "Gravitation and Cosmology", S. Weinberg.
iv) "A first course in General Relativity", B. Schutz
v) "Relativity, Gravitation and Cosmology", T. P. Cheng.

Interaction of Radiation with Matters: Detection of Charged and Neutral Particles

Departmental Elective (Credit=3)

PH5122

Full Marks: 100 **3L/ Week**

Introduction; Source of radiations.

Interaction of heavy charged particles with matter; Specific energy loss- Bethe-Bloch formula, Range, Straggling in energy loss, Range straggling, multiple scattering

Interaction of electrons with matter, Range of electrons, range determination of beta particles

Interaction of gamma radiation with matter, Compton scattering, photoelectric effect and pair production, effect of Z of the medium

Radiation exposure and dose.

General properties of the detectors: Simplified detector model, modes of operation, pulse height spectra, Energy resolution, Detector efficiency, Dead time of the detector

Gas detectors – ionization counter, proportional counter, Geiger-Muller counters

Scintillation detectors: inorganic and organic scintillator, operational principle of photomultiplier tube, quantum efficiency

Semiconductor detectors: Semiconductor properties, the action of ionizing radiation in semiconductors, operational characteristics of semiconductor detector.

Detection of neutrons, pulse shape discrimination

Statistics of counting, Binomial, Poisson and Gaussian distribution, Measurement error, Error propagation

References:

i) "Techniques of Nuclear and Particle Physics Experiments", W.R. Leo, (Springer-Verlag)
ii) "Experimental techniques in Nuclear and particle Physics", S. Tavernier, (Springer-Verlag).
iii) "Radiation detection and measurement", Glen F. Knoll, (John Wiley & Sons).
iv) "Handbook of Particle Detectors", M.K. Sunderason, (CRC Press).

Physics of Semiconductor Devices

Departmental Elective (Credit=3)

PH5123

Full Marks: 100 **3L/ Week**

1. Fundamentals of semiconductor: Idea of energy band. The Fermi level and energy distribution of carriers inside bands. Temperature dependence of carrier concentration. Carrier transport in semiconductors. Generation and recombination process of excess carriers in semiconductor and idea of quasi Fermi levels. Basic equation for semiconductor device operations.

2. P.N. junction: Energy band diagrams, built in potential & depletion width. Depletion layer capacitance. I-V characteristics for ideal diode. Majority & minority carrier concentration. Modification for real diodes. Electrical breakdown in p-n junction.

3. P-N junction devices : Majority carrier diodes: (i) Tunnel diodes: principle of operations & I-V characteristics and (ii) Schottky barrier diodes: Metal semiconductor contacts, Shottky -Mott theory & surface states, Schottky effect, current flow mechanism, I-V characteristics, Ohmic contacts. Microwaves diodes: i) Varactor, ii) IMPATT and iii)TRAPATT

4. Transfer electron device: GUNN Diode

5. Introduction to low dimensional semiconductor & Heterostructure, Q-dot, Q-wire etc. & Band gap Engineering.

6. Optoelectronic devices: (i) Photoconductor, (ii) Solar cell, (iii) Photodiode, (iv) LED, (v) Semiconductor laser, Photo transistor.

7. Power rectifiers & Thyristors, Power Mosfet, HBT (correlate with low dimensional conduction with high frequency aspects & Band gap Engineering), Basic structures, I-V characteristics & applications.

8. Semiconductor measurements: (i) Conductivity measurement: hot probe, four probe, (ii) Hall measurement: Vander Pauw arrangement, (iii) Solar cell measurement, (iv) Luminescence measurement, (v) Minority carrier lifetime measurement by photoconductive decay

References:

i) "Semiconductor devices : Basic principles", J. Singh
ii) "Solid State Electronic Devices", B. G. Streetman and S. Banerjee.
iii) "Physics of Semiconductor Devices", S. M. Zee
iv) "Semiconductor Optoelectronic Devices", P. Bhattacharya
v) "Introduction to semiconductor materials and devices", M.S. Tyagi
vi) "Semiconductor Measurements and Instrumentation", W. R. Runyan

LASER, Fiber Optics and their Applications

Departmental Elective (Credit=3)

PH5124

Full Marks: 100 **3L/Week**

I. Physics of Laser and its applications: Coherence and Monochromaticity. Line shape function and FWHM; Line broadening mechanisms: Natural broadening, Collision Broadening and Doppler broadening. Principles of light amplification: Interaction of atoms with radiation, Optical resonator (cavity), Role of feedback, Lasing action, Population inversion, Threshold condition for population inversion. Quality factor.

Laser rate equations: Two-level, three-level and four-level systems. Condition for laser operation.

Modes of Laser oscillation: Mode selection process: Transverse mode selection and Longitudinal mode selection. Production of giant pulse: Q switching technique.

Different laser systems: Gas lasers, Solid state and liquid state lasers, excimer lasers: Operation principles, Design, construction and output characteristics.

II. Optical fibers & characteristics: Transmission characteristics of Optical fibers: Ray theory Approach, Acceptance angle, Numerical aperture, Electromagnetic modal theory for optical fibers, Solving the scalar wave equation, Modal analysis of a step index fiber, Single mode and multimode fibers, modal patterns, Cut off condition, Importance of V parameter, Modal spot sizes, Fiber attenuation -: Intrinsic and extrinsic absorption losses, linear and nonlinear scattering losses, Macro bending loss and micro bending loss, splice losses and their dependence on spot sizes. Dispersion: intermodal and intra modal dispersion, material dispersion and wave-guide dispersion, design consideration of various fibers, Dispersion management in fiber optic system, different types of fibers like Dispersion shifted fiber, Dispersion compensating fiber, Dispersion slope compensating fibers in broadband system.

Fabrication of fibers: Liquid Phase techniques, vapor phase depositions, OVPO, VAD, MCVD, PCVD for pre form making and designing fiber cables.

References:

i) "Laser Fundamentals", W.T. Silfvast
ii) "Lasers: Theory and applications", K. Thyagarajan and A.K. Ghatak
iii) "Laser", O. Svelto
iv) " Laser spectroscopy", E.R. Menzel.
v) "Introduction to Fiber Optics", A.K.Ghatak
vi) "Optical Fiber Communication", J.M.Senior

Dynamical Systems-I

Open Elective (Credit=3)

PH5161

Full Marks: 100 **3L/Week**

First order autonomous systems: Basic theory, rotation, natuaral boundaries, examples from Biology.

Linear transformation of the planes: Area preserving transformations, transformation with dilation.

Second order autonomous systems: Systems of order 'n', phase flows, fixed points, equilibrium and stability, seperation of variables, classification of fixed points, determination of fixed points, limit cycles.

Conservative Hamiltonian system of one-degree of freedom: Newtonian and Hamiltonian systems, conservative systems, linear conservative systems, cubic potential, general potential, free rotation, vertical pendulum, rotation, liberation and periods, area preserving flows and Liouville's theorem.

Lagrangians: Legendre Transformation, Lagrangian equation of motion, formulation.

References:

i) "Introductio to Dynamics", I. Perseval and D. Richards.
ii) "Mathematical Methods of Classical Mechanics", V. I. Arnold, 2nd Edition, Springer-Verlag.

Basics and Applications of Quantum Mechanics

Open Elective (Credit=3)

PH5162

Full Marks: 100 **3L/week**

Pre-requisite: Idea about elementary quantum mechanics, Schrodinger's equation

Recapitulations: Historical background, Experiments demonstrating wave-matter interaction, wave packet, uncertainty principle, operators in quantum mechanics, wave function and its interpretation, normalization, Schrodinger's equation, particle in a box. (3L+1T)

Bound state and scattering problems: Harmonic Oscillator, Square and Triangular potential well, tunneling problem, Periodic potential (7L+2T)

Problems in 3D: Separation of variable, Particle in 3D box, Operators in Spherical Polar coordinates-Hydrogen atom problem. (7L+2T)

Linear vector space: Bra-Ket Algebra: application to Harmonic oscillator problem (5L+2T)

Variation method: Application to Helium atom problem (5L +1T)

Time independent perturbation: Application to Zeeman effect (5L+2T)

WKB approximation: Application to infinite and finite potential well (5L +2T)

Time dependent perturbation: Spontaneous emission (5L+2T)

References:

i) "Introduction to Quantum Mechanics", D. J. Griffiths.
ii) "Quantum Mechanics", ", B. H. Bransden and C. J. Joachain.
iii) "Quantum Mechanics", S. N Ghoshal

General Physics Laboratory

Laboratory Course (Credit=3)

PH5171

Full Marks: 100 **6hrs/Week**

1. Optics:
   - A. Intensity pattern of single and multi slit.
   - B. Fourier Optics using Crossed gratings.
   - C. Fiber Optics: Numerical Aperture and bending Loss.
   - D. Laser beam parameter measurement (Divergence, coherence, intensity spatial mode, Longitudinal modes.)

2. Solid State:
   - A. B-H loop for magnetic susceptibility.
   - B. Electrical equivalent of lattice dynamics.
   - C. Band Gap using Four Probe.
   - D. Temperature variation of reverse current.

3. Mechanics A. Parametric Oscillator.
B. Coupled Oscillator.

Computer Programming and Computational Techniques

Laboratory Course (Credit=2)

PH5172

Full Marks: 50 **3hrs/Week**

Programming: Algebraic and logical operations, Array, loops, subprogram, programming with FORTRAN/C/Python, Plotting software like gnuplot, xmgrace

Computational Techniques: Error in computation-study on error propagation, Roots of non-linear equation, Polynomial interpolation, regression and fitting, Newton-Cote's method for numerical integration, Differential equation, Solution to set of linear equations.

Electromagnetic Theory

Core Course (Credit=4)

PH5201

Full Marks: 100 **(3L+1T)/Week**

Scalar and vector potentials, Boundary value problems in electrostatics and magnetostatics, Multipole expansion of potential due to arbitrary charge distribution, Electrostatic and magnetostatic energy.

Maxwell's field equations, Coulomb and Lorentz gauge. Poynting theorem, Maxwell's stress tensor. Dispersion and absorption of EM waves, Krarmer-Kronig dispersion relation.

Propagation of EM waves in a conducting medium, optical constants of metals, discussion of wave guide and TE,TM and TEM modes, Rectangular waveguides, Cavities. Propagation of EM wave through ionosphere.

Inhomogeneous wave equation and its solution, radiation from localized source, multipole expansion in radiation zone.

Relativistic Electrodynamics: Lorentz force, energy momentum field tensor of EM field, Lagrangian and Hamiltonian of relativistic charged particle in an external EM field, covariant treatment of relativistic Lagrangian.

Lienard Wiechart potential and fields due to an arbitrarily moving charged particle. Radiation from accelerated charge. Larmor's formula and relativistic generalisation. Angular distribution of radiation emitted by an accelerated charged particle. Bremsstrahlung, Synchrotron radiation, Cerenkov effect, Thomson and Rayleigh Scattering.

Radiation damping, Abhraham Lorentz model for evaluation of radiative reaction force, line width and level shift due to radiation damping, Limitations of classical electrodynamics.

References:

i) "Classical Electrodynamics", J. D. Jackson
ii) "Classical Electricity and Magnetism", W. Panofsky and M. Phillips.
iii) "The Classical Theory of Fields", L. Landau and E. M. Lifshitz
iv) "Classical Electrodynamics", J. Schwinger, L. De Raad, K. Milton and W. Tsai

Electronic Devices and Circuits

Core Course (Credit=4)

PH5202

Full Marks: 100 **(3L +1 T)/Week**

1. Semiconductor Devices:
   (a) Charge storage and transient behaviour; Turn ON and OFF characteristics of diode; junction breakdown; hetero junction.
   (b) Characteristics of some semiconductor devices- BJT, JFET, MOS, LED, Solar cell, Photodiode, Tunnel diode, Gunn diode and IMPATT.
   (c) Transistor amplifiers- Basic design consideration; high frequency effects, Feedback in amplifiers, oscillators, series & shunt voltage regulator.
2. Op-Amp Circuits:
   Nonlinear amplifiers using op-amps- log amplifier, anti-log amplifier, regenerative comparators; Active filters; precision rectifiers; ADC and DAC circuits; Op-amp based self oscillator circuits- RC phase shift, Wien bridge, non-sinusoidal oscillators; Real op Amp. Frequency gain and band width product.
3. Passive Networks:
   Synthesis of two terminal reactive networks – Driving point impedance and admittance, Foster's reactance theorems, properties of poles and zeros of reactance function, canonic networks. Two-port network. RC Low pass and High pass filters; RC band pass filter; Band reject Filter; Impulse response in 1^{st} and 2^{nd} order ckt.; Memristors
4. Digital Circuits:
   (a) Logic functions; Logic simplification using Karnaugh maps; SOP and
   POS design of logic circuits; MUX as universal building block. Half Adder,Full Adder and array multiplier circuits.
   (b) RS, JK and MS-JK flip-flops; registers and counters.
   (c) NMOS and CMOS gates (AND, NAND and NOT)
   (d) Static and dynamic random accessmemories (SRAM and DRAM)

(e) Basics of Microcontroller and Arduino for designing innovative for innovative Physics experiment.

5. Elements of Communication Electronics:
Principles of analog modulation, Comparison among different techniques; power, bandwidth and noise immunity consideration; Generation of transmitted carrier and suppressed carrier type AM signals; VSB AM and QAM.Principles of FM and PM signal generation. Principles of detection of different types of modulated signals.

6. High Frequency Transmission Line:
Distributed parameters; primary and secondary line constants; Telegraphers' equation; Reflection co-efficient and VSWR; Input impedance of loss-less line; Distortion of em wave in a practical line.

References:

i) "Electronic Fundamental and Applications", J.D. Ryder.
ii) "Essentials of circuit analysis", R. Boylestad.
iii) "Electronics circuit analysis", Chattopadhyay and Rakshit.
iv) "Microelectronic Devices", Sedra and Smith.
v) "Op-Amps And Linear Integrated Circuits", R. A. Gayakwad.
vi) "Digital Integrated Electronics", Taub and Schilling.
vii) "Modern Digital and Analog Communication Systems", B.P.Lathi.
viii) "Network, Lines and Fields", J.D. Ryder.
ix) "Microwave Devices and Circuits", S.Y. Liao.

Quantum Mechanics - II

Core Course (Credit=4)

PH5203

Full Marks: 100 **(3L+1T)/Week**

A. Variational method - Variational inequality - Ritz variational principle - Applications to H-atom, He-atom and Linear harmonic oscillator ground states. WKB approximation - Applications to bound states and barrier penetration problems. Sudden and Adiabatic approximations and their applications.

B. Time-dependent perturbation theory - Transition amplitudes and probabilities - Constant perturbation - Transition to continuum - Fermi Golden rule - Illustrative examples. Harmonic perturbations - Emission and absorption - Single- and multi-quantum processes.

C. Elementary theory of potential scattering - Scattering cross-section and amplitude - Partial wave analysis - Phase shift and resonance - Scattering Length - Optical Theorem - Scattering by attractive square well and hard sphere potentials - Integral equation of scattering - Free-particle Green's function - Lippmann-Schwinger equation for scattering - Born approximation - Scattering by Yukawa potential - Coulomb scattering - S and T matrices. Scattering of identical particles.

D. Symmetries in quantum mechanics. conservation principles and degeneracy associated with symmetry. Continuous symmetries– spatial translation, rotation and time evolution (recapitulation). Discrete symmetries – Parity, time reversal and permutation. Spherical tensor operators. Wigner-Eckart theorem. Symmetry group and group representation.

E. Relativistic Quantum Mechanics. Klein-Gordon equation and its non -relativistic limit - inadequacies. Free particle Dirac equation. Properties of Dirac matrices. Gamma matrices. Non -relativistic limit. Co-variant formulation of Dirac equation and continuity equation. Bilinear forms. Plane wave solution and its interpretation. Application : Scattering of relativistic electrons from a nucleus - The Mott formula. Negative energy states and hole theory. Zitterbewegung. Dirac particle in a central potential. Relativistic angular momentum - how intrinsic spin of a Dirac particle comes naturally. Helicity and its significance. Radial Dirac equation and its solution for H-atom. Labelling single particle states.

F. Second Quantisation. Radiation field theory – electromagnetic field in a cavity as a collection of harmonic oscillators and its quantisation in vacuum. Occupation number representation many -boson states. Energy and momentum of the quantised field. Classical limit. Fermionic fields in second quantisation. Interaction of atom with quantised radiation field. Spontaneous and induced emission.

References:

i) "Relativistic Quantum Mechanics", J. D. Bjorken and S. D. Drell.
ii) "Advanced Quantum Mechanics", J. J. Sakurai.
iii) "Quantum Mechanics", K. T. Hecht.
iv) "Quantum Mechanics", B. H. Bransden and C. J. Joachain.
v) "Quantum Mechanics", L. I. Schiff.

Advanced Optics

Departmental Elective (Credit=3)

PH5221

Full Marks: 100 **3L/Week**

Non-linear optical phenomena. Second and third harmonic generation .Third-order non-linearities. Parametric amplification and oscillation. Laser spectroscopy – Stimulated Raman, Hyper-Raman, Coherent anti-Stokes Raman scattering. Applications of Laser.

Quantum theory of Radiation . Second quantization . Quantum statistical description of radiation fields . Coherent states. Photon correlation. Squeezed states and application. Theory of several processes using second-quantized formalism : Spontaneous and stimulated emission .

Optical fiber amplifier: Rare earth doped amplifier, dispersion compensation phenomena in optical fibers, dispersion & chirping. Non linear phenomena in optical fibers: Self phase modulation, cross phase modulation, optical soliton, non linear Schrödinger equation (NLSE), principle of optical fiber directional coupler, Fiber Bragg gratings.

References:

i) "Nonlinear Optics", R. Boyd
ii) "Introductory Quantum Optics", C. Gerry and P. L Nigh
iii) "Nonlinear Fiber Optics", G.P. Agrawal
iv) "Raman Amplification in Fiber Optic Communication", C. Headly and G.P. Agrawal
v) "Introduction to Fiber Optics", A.K.Ghatak

Computational Physics

Departmental Elective (Credit=3)

PH5222

Full Marks: 100 **3L/week**

Pre requisite: Basic knowledge in computer programming, elementary idea about classical mechanics, quantum mechanics, statistical mechanics and electromagnetic theory.

Unit1: Classical mechanical problems: Harmonic and anharmonic oscillator, effect of damping and periodic forces, Coupled oscillator, few-body problems- planetary motion, chaotic systems. (12L)

Unit2: Quantum mechanical problems: Bound state solutions, shooting method, Matrix method, scattering problems, Time evolution of eigenstate, superposition, Variational methods. (9L)

Unit 3: Electrodynamics: Boundary value problems, Partial differential equation- Numerical Solution to Laplace's equation (5L)

Unit 4: Statistical Mechanics: Random numbers, Monte-Carlo integration, Random walk problems, percolation threshold, fractals and self similarity, Approach to equilibrium, Microcanonical ensemble, Canonical ensemble, Metropolis algorithm, Phase transition-Ising Model. (16 L)

References:

i) "An Introduction to Computer simulation Methods- Application to Physical systems", (Part-1 and Part-2), H. Gould, J. Tobochnik and W. Christian.
ii) "Theoretical Physics on the personal Computer", E.W. Schmid, G. Spitz and W. Losch.
iii) "Numerical recipes in Fortran /C", W H Press, S A Teukolsky, W T Vetterling and B P Flannery

Plasma Physics

Departmental Elective (Credit=3)

PH5224

Full Marks: 100 **3L/Week**

1. Introduction: Introduction to plasma physics, Natural occurrence of plasma, Concept of temperature, density and other plasma parameters, Debye shielding.

2. Particle motion in Plasma: Motion in uniform **E** and **B** fields (E×B drift), Motion in non-uniform E and B fields (Gradient and curvature drift, Magnetic mirror)

3. Waves in Plasma: Fluid description of plasmas, Waves in unmagnetized plasma- Electrostatic waves, Electromagnetic waves, Ion-acoustic wave, Dielectric constant of field free plasma, Plasma oscillation, Magneto-hydrodynamics (MHD) approximation used in one fluid equation. MHD waves, Alfven waves and Magnetosonic wave.

4. Kinetic Description of Plasma: Elementary ideas, Microscopic equations for many body systems, Valsov equation and its properties.

5. Production of plasma in laboratory: Plasma of glow discharge, Paschen's curve and different regimes of E/p in a discharge, Single Langmuir probe, Ion acoustic wave, Thin film deposition by Magnetron plasma.

6. Nonlinear Phenomena: Definition of Nonlinearity in Dynamical system and wave phenomenon. Nonlinearity as a basic property of plasma. The effect of Nonlinearity and growth of waves due to nonlinearity. Formation of Shock, dispersion and dissipation. Balance between Nonlinearity and Dispersion. Formation of Solitary waves.

References:

i) "Introduction to Plasma Physics", F. Chen
ii) "Fundamentals of Plasma Physics", J. A. Bittencourt
iii) "Introduction of Plasma Physics", E. Buchanan
iv) "Basic Plasma Physics", B. Ghosh

Principle of Detectors and Data Acquisition Systems for Radiation Detection

Open Elective (Credit=3)

PH5261

Full Marks: 100 **3L/ Week**

Introduction; Source of radiations.

Interaction of heavy charged particles with matter; Specific energy loss- Bethe-Bloch formula, Range, Straggling in energy loss, Range straggling, multiple scattering

Interaction of electrons with matter, Range of electrons, range determination of beta particles

Interaction of gamma radiation with matter, Compton scattering, photoelectric effect and pair production, effect of Z of the medium

Radiation exposure and dose.

General properties of the detectors: Simplified detector model, modes of operation, pulse height spectra, Energy resolution, Detector efficiency, Dead time of the detector

Basic principle of Gas detectors – ionization counter, proportional counter, Geiger-Muller counters

Basic principle of Scintillation detectors: inorganic and organic scintillator, operational principle of photomultiplier tube,

Basic principle of semiconductor detectors: semiconductor properties, the action of ionizing radiation in semiconductors, operational characteristics of semiconductor detector.

Basic principle of analog and digital data acquisition system

References:

i) "Techniques of Nuclear and Particle Physics Experiments", W.R. Leo, (Springer-Verlag)

ii) "Experimental techniques in Nuclear and particle Physics", Stefaan Tavernier, (Springer-Verlag).
iii) "Radiation detection and measurement", Glen F. Knoll, (John Wiley & Sons).
iv) "Handbook of Particle Detectors", M.K. Sunderason, (CRC Press).

Physics and Applications of Quantum Structures

Open Elective (Credit=3)

PH5262

Full Marks: 100 **3L/Week**

Pre-requisite: Idea about elementary quantum mechanics, qualitative knowledge about band formation in solid.

Fundamentals: Schrodinger's equation in periodic potential, band formation, density of states in 3D. Finite size effect, surface states, density of states for quantum slab, wire and dots, Effect of quantum confinement on band structure, band gap modification. Phonons in solid, finite size effect: phonon bottleneck, Optical absorption and emission in quantum structures. (14L+4T)

Transport through quantum structures: Electrical conduction in 3D and sub 3D system, thermionic emission (Shockley and Pool-Frankel process), Hopping etc. (12L+4T)

Synthesis of quantum structures: Top down and bottom-up approaches, Lithography, sputtering, CVD, Sol Gel etc. (5L+2T)

Characterization techniques: SPM, AFM, SEM, TEM, XRD, Raman, PL (5L +2T)

Some Applications: As Light emitters and detectors, photovoltaics, sensors. (6L+2T)

References:

i) "Solid state physics", N. W. Ashcroft and N. D. Mermin.
ii) "Introduction to Nanotechnology", C. P. Poole Jr. and F. J. Owens.
iii) "Introduction to Nano Science and Nano technology", K. K. Chattopadhyay and A. N. Banerjee

Basic Electronics Circuit Laboratory

Laboratory Course (Credit=2)

PH5271

Full Marks: 100 **6hrs/Week**

A.Transistor:

1) R-C Coupled Oscillator.
2) Tuned Amplifier.
3) Multivibrator.

B.OP-AMP

1) Inverting , Non-inverting amplifier.
2) adder and substractor.
3) Differentiator and Integrator.
4) Filter Circuit
5) Wien bridge Oscillator.

C.Digital Electronics:

1) Half Adder and Full adder
2) Study of Flipflop with its truth table.
3) Converter (D2A & A2D)
4) Register.
5)Counter.

D.Constructing differential equation using electronic circuit.: Start with a oscillator ckt. such as Colpitts oscillator. Periodic doubling and chaos can be observed by changing a parameter continuously.

Atomic and Molecular Physics

Core Course (Credit=4)

PH6301

Full Marks: 100. **(3L+1T)/Week**

Structure and spectra of one-electron atoms - quantum numbers, degeneracy, parity - Atomic orbitals - Exotic and Rydberg atoms.

Fine-structure in hydrogenic spectra - mass-velocity, spin-orbit and Darwin corrections - Lamb shift - Hyperfine interactions.

Spectra of alkali atoms - spin-orbit interaction and fine-structure.

Interaction of one-electron atoms with radiation - transition probability and selection rules - allowed and forbidden transitions - Atomic oscillator strengths and sum rule - Atomic life-times and metastable states - Atomic line-broadening mechanisms.

Effects of external electric and magnetic fields on one-electron spectra - linear and quadratic Stark effects - atomic polarizability - Normal and anomalous Zeeman effects - Paschen-Back effect.

Pauli exclusion principle and spectra of two-electron atoms - ortho and para states of helium - energies of ground and excited configurations.

Many-electron atoms - Central-field approximation and corrections to it - spectroscopic terms of multielectron configurations - L-S and j-j coupling schemes - equivalent and non-equivalent electrons - Hund’s rule - Slater determinant - Hartree-Fock and Thomas-Fermi approximations.

Types of molecules and molecular spectra - Born-oppenheimer approximation - Rotational spectra of diatomic molecules - rigid and non-rigid rotator models - intensity - Symmetric top molecule - Vibrational spectra of diatomic molecules - harmonic and anharmonic oscillator models - Morse potential - Rotation-vibration coupling - different branches - Electronic spectra of diatomic molecules - structure of electronic bands - different branches - intensity - Frank-Condon principle - Raman spectroscopy - rotational and vibrational Raman spectra - theory.

References:

i) "Physics of Atoms and Molecules", B. H. Bransden and C. J. Joachain
ii) "Theoretical Atomic Physics", H. Friedrich
iii) "Quantum Mechanics of One- and Two-electron Atoms", H. A. Bethe and E. E. Salpeter
iv) "Molecular Spectra and Molecular Structure. I. Spectra of diatomic molecules", G. Herzberg
v) "Fundamentals of Molecular Spectroscopy", C. N. Banwell

Nuclear Physics

Core Course (Credit=4)

PH6302

Full Marks: 100 **(3L+1T)/Week**

Basic nuclear properties : Charge and matter distribution, shapes, parity of states, electromagnetic static moments, Binding energy, Liquid drop model (LDM), Semi-empirical mass formula, asymmetry term and pairing term. Use of the formula. Other mass formulae so far.

Two-nucleon Problem : nn, np,pp systems: The deuteron : Extraction of the nature of N-N interaction from the study of data on the bound np system, - spin, isospin dependence, role of tensor potential. Scattering length. Low-energy n-p scattering Cross-section in terms of scattering length, Wigner's hypothesis, effective range theory - spin dependence of the cross-section, coherent scattering. Postulates to derive the General form of central and tensor potential. Deuteron problem with central plus tensor potential (Rarita-Schewinger Theory), Electric quadrupole moment of the deuteron and the wave function of the ground state. Exchange forces.

Meson theory of nuclear forces -Yukawa theory. Charge independence and charge symmetry of nuclear forces - Isospin formalism.

Nuclear many-body problem: Meaning of it. Nuclear Shell Structure - evidences of shell structure, nuclear shell model with two-body forces only, Independent Particle Shell Model (IPSM) - role of spin-orbit force in producing numbers, calculation of shell gap, single particle states in major shells, intruder orbit and magic numbers. Spin- parity of the nuclear ground state in IPSM, magnetic dipole and electric quadrupole moments in odd-A nuclei.

Shell model with residual interaction - configuration mixing and consequences.

Examples of collective motions in nuclei - rotational and vibrational spectra.

Direct and compound nuclear reaction mechanisms - Cross sections in terms of partial wave amplitudes - Compound nucleus - Scattering matrix - Reciprocity theorem- Breit - Wigner one - level formula - Resonance scattering. Fission and Fusion.

Nuclear Decays: Alpha decay- Gamow's theory.

Beta decay - Angular momentum and parity selection rules - Comparative half - lives - Allowed and forbidden transitions - Selection rules - one-body operators for allowed decays - Estimates of vector and axial vector coupling constants. Super-allowed beta transitions, CVC hypothesis and unitarity of CKM matrix. Parity violation in weak interaction.

Gamma decay- Multipole transition operators and multipole transitions in nuclei - Angular momentum and parity selection rules, examples - Internal conversion - Nuclear isomerism.

Elementary Particle Physics:

Relativistic kinematics. Classification of fundamental forces and their relative strengths with how they are obtained. Elementary particles and their quantum numbers. Gell-Mann - Nishijima relation. Application of symmetry arguments to particle reactions. Parity non-conservation in weak interaction

Symmetry and conservation laws- Elementary' ideas of CP and CPT invariance - Classification of hadrons - Lie algebra, SU(2) - SU(3) multiplets - Quark model - Gell-Mann - Okubo mass formula for octet and decuplet hadrons - Charm, bottom and top quarks.

References:

i) "Nuclear Physics: Theory and experiment", R. R. Roy and B. P. Nigam.
ii) " Theoretical Nuclear Physics", J. M. Blatt and V. F. Weisskopf
iii) "Introductory Nuclear Physics", K. S. Krane
iv) "Shell-Model Applications in nuclear spectroscopy", P. J. Brussard and P. W. M. Glaudemans.
v) "Quarks, Leptons: An Introductory Course in Modern Particle Physics", F. Halzen and A. Martin
vi) "Unitary symmetry and elementary particles", D. B. Lichtenberg

Solid State Physics

Core Course (Credit=4)

PH6303

Full marks: 100 **(3L+1T) / Week**

Elastic Constants of Crystals: Analysis of stress and strain, Dilation, elastic compliance and stiffness constants, elastic energy density, Elastic stiffness constant of cubic crystals, Elastic waves in cubic crystals.

Lattice dynamics and Specific heat: Classical theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: monatomic and diatomic cases, Characteristics of different modes, long wavelength limit,Optical properties of ionic crystal in the infrared region; Inelastic scattering of neutron by phonon;Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity; Anharmonic effects in crystals - thermal expansion

Free electron theory of metals: Free electron gas model of metals, free electron gas in a one-dimensional box, free electron gas in a three dimensional box, filling up of the energy levels, Density of electron States, the Fermi energy, average kinetic energy of an electron, average velocity of an electron.

Application to transport properties: The Boltzmann transport equation, electrical eonductivity, Drude Lorentz theory, Sommerfield theory, thermal conductivity, Weidemann- franz law, Hall effect.

Band theory of solids: Wave functions in a periodic lattice and the Bloch theorem, The Kronig-Penny model , Approximate solution near a zone boundary and band gap, the tight binding approximation, cyclotron resonance, the De-Haas Van Alphben effect. Band theory of insulators and semiconductors, Intrinsic semiconductors, Band model.

Extrinsic Semiconductors, impurity states and band model, measurement of band gap- the infrared absorption in band gap. Introduction to Polaron, Introduction to disordered solid.

Superconductivity and Superfluidity: Electromagnetic properties of superconducting states – T_C, H_C, Meissner effect, London's phenomenological theory and penetration depth, coherence length, Type-I and Type-II superconductors, magnetic flux quantization. Thermodynamic properties – condensation energy, entropy, electronic specific heat. Isotope effect. BCS theory of superconductivity, Cooper pairs. AC and DC Josephson effects. High-T_C superconductors.

Superfluidity of liquid He^4, The λ transition, Tisza's two-fluid model, Landau's theory.

References:

i) "Introduction to solid state physics", C. Kittel.
ii) "Solid state physics", N. W. Ashcroft & N. D. Mermin.
iii) "Solid state physics", A. J. Dekker.
iv) "An Introduction to Lattice Dynamics", A. K. Ghatak and L. S. Kothari
v) "Statistical Mechanics", (Second Ed.), K. Huang

Advanced Laboratory

Laboratory Course (Credit=3)

PH6371

Full Marks 100 **6hrs/Week**

1. Studies on Lande-g factor using Electron Spin Resonance Spectrometer.
2. Studies on velocity and compressibility in a liquid using Ultrasonic Interferometer.
3. Studies on wavelength and air spacing of etalon for a given laser source using Febry - Perot Interferometer.
4. Studies on wavelength of sodium D-lines and estimate the separation between Na -D1 and D2 lines using Michelson Interferometer.
5. Studies on Verdet constant of flint glass using Faraday Effect Setup.
6. Studies on Bohr magneton using Zeeman Effect Set up.
7. Studies on magnetic susceptibility of a paramagnetic material using Guoy's method.
8. Studies on Opto-electric effect using Kerr Effect.
9. Studies on statistical nature of radioactive decay process
   (Apparatus: Radioactive source, Geiger Muller Counter)
10. Studies on β-absorption for different radioactive sources.
   (Apparatus: Radioactive source, Aluminium absorber and Geiger Muller Counter).
11. Electro-optics/modulation/switching
12. Second Harmonic Generation

Statistical Mechanics

Core Course (Credit=4)

PH6401

Full Marks 100 **(3L+1T)/Week**

i) Foundations of statistical mechanics: macrostate, microstate, phase space and ensemble, connection between statistics and thermodynamics, phase space trajectories and density of states, phase space, trajectories and density of states, Liouville’s theorem, ergodic hypothesis, Concept of entropy, Microcanonical ensemble, classical ideal gas, entropy of mixing and Gibb's paradox.

ii) Canonical and grand canonical ensembles; partition function, Free energy, calculation of statistical quantities, energy and density fluctuations, chemical potential, Saha ionization equation.

iii) Quantum statistical mechanics: Density matrix, statistics of indistinguishable particles, Maxwell-Boltzman, Bose- Einstein and Fermi-Dirac statistics, properties of ideal Bose and Fermi gases, Bose-Einstein condensation, white dwarfs.

iv) Cluster expansion for a classical gas, Virial equation of state,

v) Phase transitions and critical phenomena: Ising model - mean-field theory and exact solution in one-dimension. Landau theory of phase transition, critical indices, scale transformation and dimensional analysis. Elementary ideas of renormalization group.

vi) Brownian motion, Langevin theory, fluctuation dissipation theorem, Fokker-Planck equation.

Reference:

i) “Statistical Mechanics”, (Third Ed.), R. K. Pathria

ii) “Statistical Mechanics”, (Second Ed.), K. Huang

iii) “Statistical Physics”, L. Landau and E. M. Lifshitz

iv) “Statistical Physics of Particles and Fields”, M. Kardar

Physics of Materials

Departmental Elective (Credit =3)

PH6421

Full Marks: 100 **3L/Week**

Material Preparation and Characterization: Preparation of materials by different techniques: Bulk crystal growth, Epitaxial growth, Thermal and electron evaporation technique, Sputtering, CVD, Melt and quenching, Gel desiccation. Characterization of material by XRD, thermal methods (DSC, DTA), Optical method (IR, FTIR, Raman), Microscopic (SEM, TEM, STEM, AFM etc.). Mechanical and electrical methods. Non destructive testing.

Structure of Materials: Atomic structure and interatomic bonding, Structure of crystalline solids, structure of non-crystalline solids (SRO and MRO); Radial distribution funcdtion, Solid solutions. Phases, Thermodynamics of solutions, Phase rule, Binary phase diagrams, Binary isomorphous systems, Binary eutectic systems, ternary phase diagrams, kinetics of solid state reactions.

Dielectric and Optical properties of materials: Theory of Electronic polarization and optical absorption, Ionic polarization, orientational polarization. Optical phonon mode in an ionic crystal: Interaction of electromagnetic waves with optical modes, Polariton, Dispersion curves of Transverse Optical (TO) phonon and optical photon in a diatomic ionic crystal, LST relation.

Ferroelectric crystal: Theory of ferroelectric phase transition- first order and second order phase transitions and their characteristics. Luminescence, Fluorescence, Phosphorescence, Raman scattering, Spectroscopic techniques.

Physics of Semiconductors: Semiconductor materials- elemental & compound semiconductors & their properties Intrinsic & extrinsic semiconductors. Degenerate & compound semiconductors. Direct & indirect band gap semiconductors. Variation of energy bands for gr III– V ternary, quaternary alloys with alloy composition Concepts of Fermi level, Drift & Diffusion of carriers conductivity & mobility. Effect of Temp. and Doping. Hall effect in semiconductors. LED, Semiconductor laser, Photo diode and Photo detector.

Functional Materials: Periodic dielectric, periodic magnetic materials, smart materials, Multiferroics.

References:

i) "Physics of Semiconductor devices", S.M.Sze
ii) "Solid state electronic devices", S. Banerjee & B. G. Streetmann
iii) "Introduction to semiconductor materials and devices", M. S. Tyagi
iv) "Introduction to solid state physics", C. Kittel
v) "An Introduction to crystallography", F. C. Philips
vi) "Material Science and Engineering: An introduction", W. D. Callister, Jr.
vii) "Solid state physics", N. W. Ashcroft & N. D. Mermin
viii) "Solid state physics", J. S. Blakemore
ix) "Elements of solid state physics", J.P.Srivastava
x) "Molecular structure and spectroscopy", G. Aruldhas
xi) "Principle of fluroscence spectroscopy", J.R. Lakowicz
xii) "Fundamentals of molecular spectroscopy", C.Banwell & E.Mccash
xiii) "Measurement, Instrumentation and Experimental Design in Physics and Engineering", M Sayer and A Mansingh

Nuclear Physics and Nuclear Astrophysics

Departmental Elective (Credit=3)

PH6422

Full Marks: 100 **3L/Week**

1. Collective nuclear models: Vibrational Model and rotational Model

2. Advanced experimental nuclear techniques: Evaluation of nuclear level scheme, angular distribution and polarization measurements, measurement of the lifetime of nuclear states.

3. Advanced nuclear structure and reactions: Yukawa theory of N-N interaction - OPE potential-Fermi gas model of the nucleus and applications - Transfer reactions - stripping and pick-up reactions - calculation of cfp (coefficient of fractional parentage) - experimental determination of the structure of the nuclear states.

4. Nuclear Astrophysics: Primordial nucleosynthesis - Maxwellian averaged reaction cross-section in stellar plasma - Gamow peak and Gamow window - astrophysical S-factor - derivation of an analytic expression for the thermally averaged cross-section - temperature dependence of cross-section.

5. Hydrostatic Burning phases of a star: Energy generation and nucleosynthesis - pp chain and CNO cycle - self-regulatory processes in H-burning - beta decay in stellar plasma - triple - α reaction and Hoyle state - concept of network calculation of nucleosynthesis - main processes of nucleosynthesis in the Universe beyond Fe - the r-process, s-process and p-process.

References:

i) "Nuclear Physics", R R Roy and B P Nigam.
ii) " Nuclear Physics", Samuel S. M. Wong.
iii) "Structure of the Nucleus", M. A. Preston and R. K. Bhaduri.
iv) "Introductory Nuclear Physics", K. S. Krane.
v) "Nuclear physics of stars", C. Illiadis.
vi) "Cauldrons in the Cosmos", C. E. Rolfs and W. S. Rodney
vii) "Shell-Model Applications in nuclear spectroscopy", P. J. Brussard and P. W. M. Glaudemans

Field Theory and Particle Physics

Departmental Elective (Credit=3)

PH6423

Full Marks: 100 **3L/Week**

Part A – Quantum Field theory

1. Free field theory and canonical quantization: (6)
   Lagrangian, symmetries and conservation laws, Noether' s theorem,
   Real and complex scalar fields, Dirac field and electromagnetic field – canonical quantization.
2. Interacting field theory: (5)
   Interaction picture, covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.
3. QED: (6)
   Feynman rules, Calculation of the processes: Rutherford, Bhabha, Moeller, Compton and $e^+e^- \rightarrow \mu^+\mu^-$, Decay and scattering kinematics, Mandelstam variables and crossing symmetry.
4. Renormalization: (3)
   Basic ideas of regularization and renormalization, renormalization in $\lambda\varphi^4$ theory, elementary discussion of renormalization group.

Part B – Particle Physics

5. Lorentz and Poincare group: (3)
   Continuous and discrete transformations, Elements of group structure, Proper and improper Lorentz transformations, SL (2, C) representation of Lorentz group, Poincare group, Classification of particle states.
6. Gauge theory: (5)
   Principle of gauge invariance, Abelian and non-abelian gauge theories, spontaneous symmetry breaking, Higgs mechanism.
7. Weak interaction: (3)

Fermi theory, decay widths of μ and π, Neutrino oscillation

8. Strong interaction: (4)
   Elastic e-p scattering, electromagnetic form factor, Deep inelastic scattering, structure function, scaling, sum rules, QCD and asymptotic freedom, gluons and jets in $e^+e^- \rightarrow$ hadrons, scaling violation.
9. Standard model: (5)
   Symmetries and Lagrangian , Quark mixing, absence of FCNC, CKM matrix, Kaon oscillation, CP violation.

References:

i) "Relativistic Quantum Mechanics and Fields", J. D. Bjorken and S. D. Drell
ii) "An Introduction to Quantum Theory of Fields", M. Peskin and D. Schroder
iii) "Quantum Field Theory", C. Itzykson and J. B. Zuber
iv) "Quarks and Leptons", F. Halzen and A. D. Martin
v) "Gauge Theory of Elementary Particles", T-P Cheng and L-F Li
vi) "A First Book of Quantum Field Theory", A. Lahiri and P. B. Pal.

Advanced Condensed Matter Physics

Departmental Elective (Credit=3)

PH6424

Full Marks: 100 **3L/Week**

1. Quantization: First quantization of single-particle and many-particle systems. Basic concept of second quantization, occupation number representation, Bosonic and Fermionic operators. Operators for kinetic energy, Coulomb interaction, spin, density, and current.

2. The electron gas: Non-interacting electron gas in a static ion lattice, Bloch theorem. 1st order and 2nd order perturbation theory for interacting electron system. Basic concept of mean field theory. Hartree–Fock approximation for homogeneous electron gas. Broken symmetry & Ferromagnetism.

3. Green's functions: Single-particle Green's functions of many-body systems. The spectral function, broadening of the spectral function. Tunneling spectroscopy, Optical spectroscopy. Anderson's model for magnetic impurities. Two-particle correlation function, Random Phase Approximation (RPA). Finite temperature Green's functions/Imaginary time Green's functions, Definitions of Matsubara Green's functions, Matsubara frequency, connection between Matsubara and retarded functions. Many particle Green's functions to one particle Green's functions, Wick's theorem. Feynman diagrams for non-interacting particles in external potentials, impurity scattering, pair interactions. Self-energy and Dyson's equation.

4. Transport in mesoscopic systems: Kubo formula for conductivity, dielectric function for translation-invariant system. S-matrix and Landauer-Buttiker formula.

5. Fermi liquid theory: Basic concept, calculation of specific heat, magnetic susceptibility, sound velocity, one dimensional electron gases and Luttinger liquids.

6. Hubbard Model: Formulation of the theory, application in transition metal monoxide (FeO, NiO, CoO), heavy fermion system, high temperature Superconductor. Bose Hubbard model and Bose–Einstein condensate.

7. Model dielectric functions: Thomas-Fermi, LDA, Hubbard

8. Localization: Strong localization, Anderson transition. Weak localization.

9. Quantum Phase Transitions: Quantum Rotor Model, Scaling, Mean-Field Solution and Landau-Ginsburg theory.

References:

i) "Many-Particle Physics", (3rd edition), G. D. Mahan.
ii) "Many-Body Quantum Theory in Condensed Matter Physics", H. Bruus and K. Flensberg.
iii) "Quantum Theory of Many-Particle Systems", A. L. Fetter, and J. D. Walecka.
iv) "Quantum Field Theory and Condensed Matter: An Introduction", R. Shankar
v) "Condensed Matter in a Nutshell", G. D. Mahan.

Special Laboratory for Condensed Matter Physics

Laboratory Course (Credit=3)

PH6471

Full Marks: 100 **6hrs/Week**

1. Studies on Photoconductor(LDR)
2. Studies on Phase Transition in Ferrite Material
3. Studies on Phase Transition in PZT
4. Studies on Light Emitting Diode (LED)
5. Studies on Diode Laser
6. Studies on Hall Effect
7. Studies on Photovoltaic Cell
8. Studies on magneto-resistance of a given semiconductor sample.
9. Studies on Thermo luminescence of F-centre in alkaline halide crystal.
10. Studies on Polarization Electric field (PE) hysteresis loop of PZT sample at different temperature.
11. Studies on BE hysteresis loop of ferrite sample at different temperature.

Special Laboratory for Nuclear and Particle Physics

Laboratory Course (Credit=3)

<u>PH6472</u>

Full Marks: 100 **6hrs/week**

Expt.1: study the gamma spectra in integrated and differential mode for a given radioactive source using Single Channel Analyser (SCA) [Apparatus: Radioactive source, Single Channel Analyser and Scintillator (NaI) detector].

Expt. 2: study the gamma spectra for a given radioactive source using Multi Channel Analyser (MCA) [Apparatus: Radioactive source, Multi Channel Analyser and Scintillator (NaI) detector].

Expt. 3: Study the effect of radiation shielding on gamma spectroscopy [Apparatus: Radioactive source, Multi Channel Analyser, Lead (Pb) Shield and Scintillator (NaI) detector].

Expt.4: Study the energy and timing spectra for a given radioactive source using 200 MHz digital oscilloscope [Apparatus: Radioactive source, Scintillator (NaI) detector and 200 MHz digital oscilloscope].

Expt. 5: Study the angular correlation between 1173 keV and 1332 keV transitions emitted from 152Eu using 100MHz digitizer [Apparatus: 152Eu radioactive source, Scintillator (NaI) detector and 100 MHz digitizer].

Expt.6: Study the energy and timing response of CeBr3 detector [Apparatus: Radioactive source, CeBr3 detector and 500 MHz digitizer].

Expt. 7: Study the coincidence relationship between the decay out gamma transitions from a given radioactive source [Apparatus: Radioactive source, CeBr3 detector and 500 MHz digitizer].

Expt. 8: Measurement of the impurities and their relative amount present in a given sample using X-ray Fluoresce (XRF) technique. [Apparatus: X-ray source, Si PIN detector and digitizer].

Simulation: Study of the interaction of charged particles with matter using SRIM/TRIM code

a) For different projectiles of same energy and with same target material.

b) For a projectile of different energies and with same target.

c) For a projectile of definite energy and with different target materials.

List of instruments/sources/samples used:

1. Radioactive sources: ^{22}Na, ^{57}Co, ^{60}Co, ^{90}Sr-^{90}Y, ^{133}Ba, ^{137}Cs, ^{204}Tl

2. Geiger Muller Counter.

3. Scintillation (NaI) detector with Single Channel Analyzer & Counter.

4. Scintillation (NaI) detector with Multi Channel Analyzer & Counter.

5. Lead (Pb) shield.

6. CeBr3 detectors.

7. 100 MHz and 500 MHz Digitizer.

8. 100 MHz, 2 channel and 200 MHz, 4 channel digital oscilloscope.

9. X-Ray Fluorescence Spectrometer (XRF).